Millimeter and Submillimeter Wavelength Studies of Nitric Acid's ν_6, ν_7 and ν_8

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By

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ABSTRACT

Millimeter and submillimeter–wave studies have been performed on the HNO_3 molecule by means of a **FA**st **S**can **S**ubmillimeter **S**pectroscopic **T**echnique (FASSST). An ISTOK OB-30 BWO was used to take fast scans of the region 245–370 GHz. Over 500 spectral lines due to rotational transitions have been assigned for the HNO_3 or nitric acid in the ν_6, ν_7, and ν_8 vibrational states.
A Watson S- and A- reduced Hamiltonian and non–linear least squares fitting procedures were used in the analysis of the measured HNO_3 lines.
The rotational constants and rms deviations for each vibrational mode are reported.

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CHAPTER 1

INTRODUCTION

Nitric Acid has been the subject of a number of spectroscopic investigations because of its chemical significance and its presence in numerous physical systems of practical importance. It is both a common chemical species and an important minor constituent of the terrestrial atmosphere. Spectral features of nitric acid (HNO_3) were first discovered in the Earth's atmosphere by Murcay *et al.*(1), who initially detected the Q branch of the 7.5 um band. As a result HNO_3 has received considerable spectroscopic attention, both in the microwave and infrared spectral regions $(1 - 14)$. For example, this laboratory has studied the complex spectra of this molecule for well over fifteen years. We have previously analyzed the rotational spectrum of HNO_3 ground vibrational state, ν_6 at $647cm^{-1}$, ν_7 at $579cm^{-1}$, and ν_8 at $762cm^{-1}(2, 3, 7 - 11)$. A new Fast Scan Submillimeter Spectroscopic Technique (FASSST) has been developed to replace the more traditional phase locked frequency techniques to measure lines. The advantage of the FASSST system is that it can measure literally thousands of lines in a matter of seconds. The FASSST system is based on the Backward Wave Oscillator (BWO) Tube as the coherent radiation source. In this report we shall add the FASSST spectra (240-370 GHz)to the previous measurements to compile a more complete and accurate tool for remote sensing of the upper

atmosphere. Also, this experiment will be a good barometer of how well the FASSST system acquires spectra. The ν_6, ν_7 and ν_8 vibrational states have not shown any evidence of perturbation. In all cases, the theoretical fit to the experimental data has been exactly as we have expected.

Nitric acid is a near-oblate asymmetric rotor with strong a-type and weaker b-type transitions. The large dipole moment and rotational constants of the order of 10 GHz and moderate centrifugal distortion contribute to a dense spectrum which is further complicated by the thermally populated vibrational states. The ground state rotational spectrum has been extensively investigated in the past and is well understood. It was studied in the centimeter-wave region by Millen *et al.*(4, 5), and by Cox *et al.*(6). The ground state analysis has been extended into the millimeter and submillimeter wave regions by Cazzoli and De Lucia (7), Bowman, Helminger, and De Lucia (8), Messer, Helminger, and De Lucia (9). Recently, Goyette *et al.*(15 − 17) and Paulse *et al.*(18) studied the effects of pressure broadening on HNO_3 and torsional splitting of its excited vibrational states in the millimeter and submillimeter wave regions.

Each molecule has its own unique spectral signature which is dependent on intermolecular interactions. This makes mm/submm wave spectroscopy a valuable tool used to observe and identify molecules that exist in the atmosphere. Nitric acid has peak rotational absorption in the mm/submm wave region. The near degeneracy of many strong lines in each branch of the ground state provides easily identifiable spectroscopic features: airborne observations of stratospheric emission spectra have detected these features (9, 19). This makes nitric acid a prime candidate for remote sensing.

CHAPTER 2

Experimental

Figure (2.1) shows the FASSST system, which uses a voltage tunable BWO as a primary source of radiation, is equipped with an ISTOK OB-30 to cover the 240-370 GHz region. There are two wire grid polarizers. The first polarizer is used to provide a well defined polarization from the output of the overmoded BWO waveguide. The second polarizer is used to split the power of the output of the BWO into the absorption cell and a folded 38.89 m Fabry-Perot (FP) cavity. The cavity is equipped with a mylar beamsplitter which provides fringes for frequency interpolation between reference spectral lines of known frequency. Also there are three InSb photoconduction detectors with three collecting horns to help focus the beam while it travels through the main cell, reference cell, and the FP cavity. These and other aspects of the FASSST system are discussed in detail by Petkie *et al.*(20). The focus here will be on the frequency calibration scheme (21).

The idea for frequency calibration is simple. A fraction of the BWO power is coupled into a FP cavity that generates sharp resonances when an integral number of half wavelengths exists in the cavity (22, 23). As the BWO frequency is swept, the

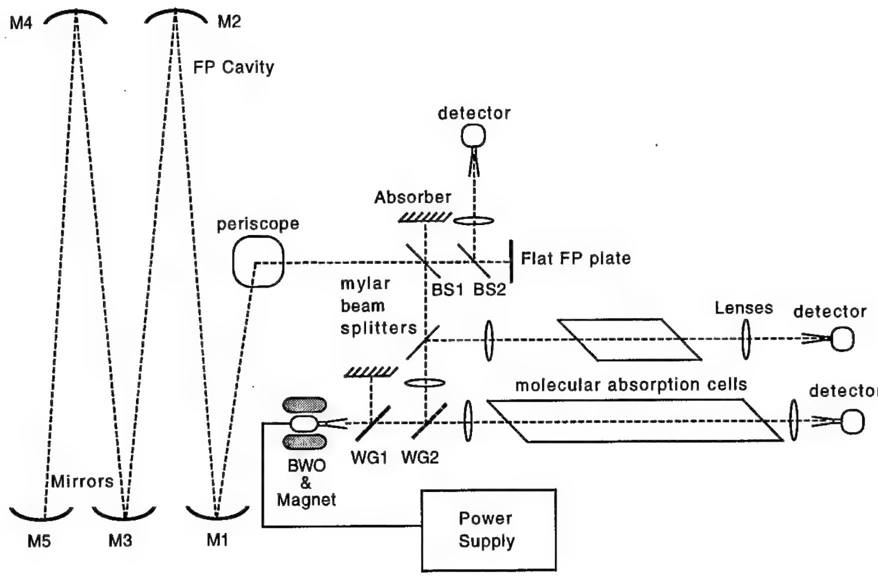


Figure 2.1: The FASSST Spectrometer.

FP cavity modes have a spacing in frequency of,

$$\Delta = \frac{c}{2nL},$$

where c is the speed of light, L is the length of the FP cavity, and n is the index of refraction ($n = 1$). For the current design of FASSST, $L \approx 39$ m, and the FP cavity mode spacing is $\Delta \approx 3.854$ MHz.

The frequency calibration scheme could be as simple as having two spectral lines of known frequency somewhere near the opposites ends of the range of frequencies measured and using linear interpolation. However, since the frequency of the BWO is not a linear function of voltage this, straightforward method is not applicable. The small scale structure of the frequency-voltage foundation of the BWO is complex and

creates the first obstacle to accurate calibrations. If the effects of small scale structure are not treated properly, the accurancy of the FASSST system will be approximately 1000 times worse than the required specifications for high resolution spectroscopy. One useful test of linearity is to remove every other FP mode and see how well predicted it is from the remaining modes assuming the frequency is linear between the remaining modes. One can also use every n^{th} mode to calculate the skipped modes in between FP modes and see how well predicted they are. These test show that non-linearites introduced a $<< 0.1$ MHz of measurement error into the FASSST system. However, with a small FP mode spacing a simple linear interpolation method can be used to measure line frequencies to $\sim \frac{1}{10}$ of the Doppler limited linewidth. If the linear interpolation frequency calibration is to be accurate two important assumptions must be made about the FP cavity:

- the FP mode spacing, Δ, does not vary with frequency,
- and the frequency between two adjacent FP modes can be calculated by a linear interpolation.

The first assumption is valid as long as the FP cavity is carefully designed and no dispersive effects such as water absorption exists. The second assumption depends on the small scale f/v characteristics of the BWO, which must be linear between the FP cavity mode spacing. A non-linearity between FP modes may originate from two different sources: non-linearities in the voltage sweep or a fundamental non-linearity of the f/v characteristics of the BWO. The first effect may be accounted for by scanning at a fast enough rate so that the time between FP modes is short compared to the fundamental frequency on the non-linear voltage. The effect is caused by power supply ripples induced from the 60 Hz AC line; however, when the sweep is

fast enough the BWO freezes the instabilities associated with the power supply and thermal drift. The second consideration involving the characteristics of the BWO can be accounted for by increasing the length of the FP cavity which decreases the distance in frequency between the FP modes. Based on these considerations, the basic FASSST scheme is to: (1) take a fast ($10^4-10^5 MHz/sec$) scan over the spectral region of interest, (2) include two or more (typically$\sim$ 50 are available) reference lines, (3) use the known frequencies of the reference lines to determine the FP cavity mode spacing and absolute frequency, (4) count FP modes to establish the frequency of each fringe, and (5) use linear interpolation between the two nearest FP modes to calculate the frequencies of the unknown lines (20).

CHAPTER 3

Asymmetric Rotor Theory

The rotational spectra of molecules are classified as arising from four different molecular structures: diatomic molecules, linear polyatomic molecules, symmetric top molecules, and asymmetric top molecules. It is essential when studying the rotational spectra of molecules that they are categorized according to their principal moments of inertia.

The moment of inertia I of any molecule about any axis through the center of mass is given by

$$I = \sum_i m_i r_i^2 \tag{3.1}$$

where m_i and r_i are the mass and distance of atom i from the axis. There are three principal axes of inertia a, b, and c with three corresponding moments of inertia I_a, I_b, and I_c. These axes are mutually perpendicular to one another. According to convention the a axis has the minimum value of the moment of inertia, while the c axis has the maximum value of the moment of inertia. The b axis is greater than the a axis, but smaller than the c axis, such that

$$I_c \geq I_b \geq I_a$$

3.1 Linear Polyatomic and Diatomic Molecules

Linear Polyatomic molecules and diatomic molecules can be treated with the same method. Namely, we shall consider rigid body rotation in space-fixed axes, then small internal vibrations of the nuclei in the ground electronic states, and finally all the degrees of freedom coupled together in electronic spectra. The rotational energy of a rigid body in free space is purely kinetic, so (24)

$$E_{rot} = \frac{1}{2}\sum_i m_i(\dot{x}_i^2 + \dot{y}_i^2 + \dot{z}_i^2). \tag{3.2}$$

This energy is equivalent to that for motion about the three principal axes, each with its associated moment of inertia, in space. The three axes intersect at the center of mass of the molecule. If w_j is the angular velocity about each of these axes, then the rotational energy is given by

$$E_{rot} = I_a\omega_a^2 + I_b\omega_b^2 + I_c\omega_c^2 \tag{3.3}$$

where I_a , I_b, and I_c are the moments of inertia as stated above.

The axis of rotation for diatomic and polyatomic molecule is taken to be the b-axis. The rigid rotor energy levels are given by

$$E_{rot} = BJ(J+1) \tag{3.4}$$

where J is the total angular momentum quantum number and may take on any positive integral value. The rotational constant B is equal to $\frac{\hbar^2}{2I_b}$ and the total angular

momentum is $P = [J(J+1)^{\frac{1}{2}}]\hbar$. Absorption or emission of microwave energy occurs for $\triangle J = +1$. Using Bohr's postulate (25)

$$E_{J'} - E_J = h\nu \tag{3.5}$$

and $J' = J + 1$, we conclude that the frequency absorbed by a transition between these two energy levels is given by

$$\nu = 2B(J+1) \tag{3.6}$$

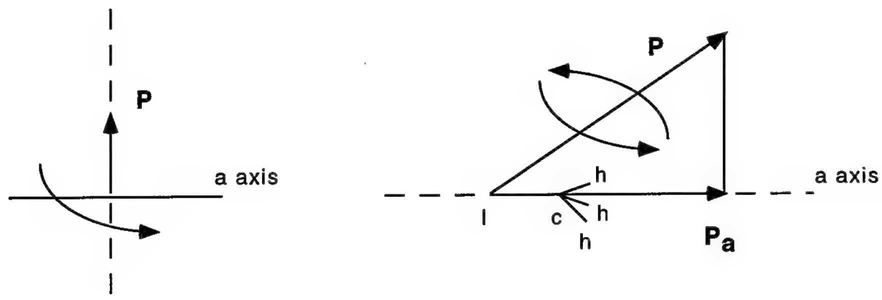
The spacing between adjacent absorption lines is equal to 2B.

In diatomic molecules deviations from these equally spaced lines are well accounted for by a vibration-rotation interaction. This occurs when the molecular bond length is being stretch away from its equilibrium position by centrifugal force in a rotating molecule. The faster the molecule rotates the further the masses are displaced from the equilibrium position, leading to an increase in the moment of inertia. The rotation energy of the distorted molecule, including the displacement from equilibrium, is

$$E_{rot} = BJ(J+1) - DJ^2(J+1)^2 \tag{3.7}$$

where D is the centrifugal distortion constant and is always positive for diatomic molecules. The corrected absorption frequency is

$$\nu = 2B(J+1) - 4D(J+1)^3. \tag{3.8}$$



(a) The rotational angular momentum vector P for a linear molecule

(b) Prolate symmetric rotor CH_3I where P_a is the component along the a axis

Figure 3.1: A Prolate Symmetric Rotor

3.2 Symmetric Rotor

The symmetric-top rotor has two of the principal moments of inertia that are equal and the third is non-zero. There exist two ways in which this can happen. The prolate symmetric top molecules are one solution, in which $I_a < I_b = I_c$ and $A > B = C$. A prolate top is of the general shape of a football or of a cigar. The other possibility is the oblate symmetric top, in which case $I_a = I_b < I_c$ and $A = B > C$. An oblate top is of the general shape of a hockey puck or a flying saucer.

In a diatomic or linear polyatomic molecule the rotational angular momentum vector $\mathbf{P}$ lies along the axis of rotation. In a prolate (oblate) symmetric rotor, $\mathbf{P}$ need not be perpendicular to the $a(c)$ axis. In general, it takes up any direction in space and the molecule rotates around $\mathbf{P}$, pictured in Fig(3.1). The component of $\mathbf{P}$ along the a axis is P_a which can only take the values $\hbar K$. This is the projection of

the total angular momentum on the symmetry axis. The rotational term values are given by (26)

$$E_{rot} = BJ(J+1) + (Z-B)K^2 \tag{3.9}$$

where K is a second rotational quantum number. The variable Z corresponds to A and C for the prolate and oblate cases, respectively. The quantum number K, being a projection of J on the principal axis, can take on values ranging from J to $-J$ in unit steps. Thus to find the total number of J sub levels, we first note that each J level has $(2J+1)$ K states, corresponding to the different possible projections of J on a molecule-fixed axis. Each(J, K) level then has the usual $(2J+1)M_J$ levels, corresponding to the different possible projections of J on a space-fixed axis. Thus the statistical weight for each J level is $(2J+1)^2$, rather than the $(2J+1)$ appropriate to a linear rotor. In a spherical top molecule, all of the $(2J+1)^2$ levels are truly degenerate because $(Z-B)$ is zero

When the centrifugal distortion effects are taken to account, we have

$$E_{rot} = BJ(J+1) + (Z-B)K^2 - D_J J^2(J+1)^2 - D_{JK}J(J+1)K^2 - D_K K^4 \tag{3.10}$$

where D_J, D_{JK}, and D_K are the centrifugal distortion constants which are small compared with A, B, and C. The D_J term results from the stretching caused by end-over-end rotation of the molecule, the D_K term results from distortion due to rotation about the symmetry axis, and the D_{JK} term results from the interaction of these two motions.

The selections rules for transitions between energy level for a symmetric rotor are $\triangle J = 0, \pm 1$. Rotational absorption transitions correspond to $\triangle J = +1$. Applying Bohr's postulate again, we derive the formula for the rotational absorption frequencies

$$\nu = 2B(J+1) - 4D_J(J+1)^3 - 2D_{JK}(J+1)K^2 \tag{3.11}$$

where J is the quantum number of the lower transition level.

3.3 Asymmetric Rotors

An asymmetric rotor has all principal moments of inertia unequal.

$$I_c \neq I_b \neq I_a \tag{3.12}$$

However, many asymmetric rotors are near-oblate asymmetric

$$I_c > I_b \simeq I_a$$

or near-prolate asymmetric

$$I_c \simeq I_b > I_a$$

.

An asymmetric rotor can be characterized by a parameter

$$\kappa = \frac{2B - A - C}{A - C} \tag{3.13}$$

which can take on values between +1 and -1. If κ is near -1, then the rotor is near prolate, and we can use K_p as a good quantum number. The small asymmetry produces a splitting of energy levels for which $K_p > 0$. Similarly, if κ is near +1, then the rotor is near oblate, and we can use K_o as a quantum number: again, there will be an asymmetry doubling for $K_o > 0$. The rotation states are labeled as J_{K_p,K_o}, where K_o and K_p are the K values that the molecule would have in the limiting oblate

and prolate cases, respectively. Nevertheless, by connecting K levels for a given J of the limiting prolate symmetric top with those of the limiting oblate symmetric top in the ordered sequence-highest to highest, next highest to next highest, and so on, as indicated in Fig(3.2) - one may obtain a qualitative indication of the levels of the asymmetric rotor. This chart also reveals the significance of the aforementioned King, Hainer, and Cross notation (27).

Basically asymmetric rotors can be split into three categories depending on the amount of asymmetry: very asymmetric, nearly prolate, and nearly oblate. There are no simple closed form expressions that can be written for asymmetric molecule due to the fact that the three moments of inertia are not equal to one another. However, the energy levels can be determined since the Schrodinger equation possesses non-trivial solutions for the expansion coefficients only for certain values of λ. The special values of λ, the allowed energy levels for an asymmetric rotor, are those for which the secular determinant vanishes $|H - \mathbf{I}\lambda| = \mathit{0}$ where $\mathbf{I}$ is a unit matrix. This eigenvalue problem can be solved by diagonalizing the Hamiltonian matrix (27). The resulting diagonal elements are then the energy eigenvalues associated with the rotational Hamiltonian H.

3.4 Vibrational States of Nitric Acid

A molecule has 3N-6 normal modes of vibration, where N is the number of constituent atomic species that comprise the molecule. HNO_3 is composed of 5 atomic species; giving N=5. Therefore there are 9 normal modes of vibration. These are labeled as V1 through V9. McGraw, Bernitt, and Hisatsume (28) mapped out the energies of these vibrational states, included overtones and combinations of these

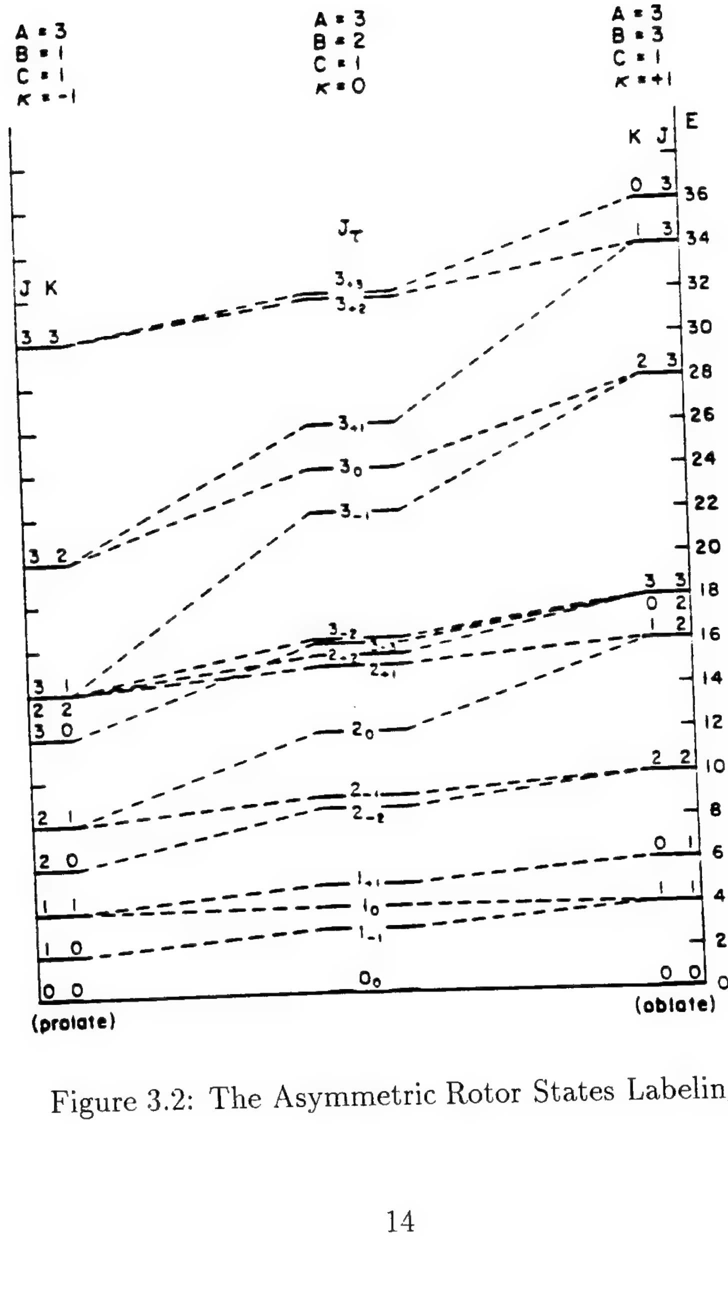


Figure 3.2: The Asymmetric Rotor States Labeling

states. A list of these vibrational states which include the structural motions that give rise to each state is given in Table (3.1).

We have previously investigated the millimeter-wave rotational transitions of V_6, V_7, and V_8. These are three of the lower lying vibrational states. The reasons these states were chosen are because they are unperturbed by other vibrational states and these levels are located lower in energy. As a result they are thermally populated by Boltzmann statistics at room temperature $e^{\frac{E_v}{kT}}$, thus giving rise to the strongest excited vibrational state rotational transitions.

Table 3.1: Vibrational Modes of Nitric Acid.

Mode	Energy(cm^{-1})	description
ν_1	3550.0	OH stretch
ν_2	1705.6	NO antisymmetric
ν_3	1330.7	HON bend
ν_4	1324.9	NO symmetric stretch
ν_5	878.6	NO_2 deformation
ν_8	762.2	NO_2 out of plane
ν_6	646.6	NO' stretch
ν_7	579.0	ONO' bend
ν_9	455.8	NO_2 torsion

CHAPTER 4

Analysis

We have used Watson's reduced centrifugal distortion Hamiltonian in its A and S form for all our analyses of the vibrational states of nitric acid (14). Through terms of the 8th order in the angular momentum, the Hamiltonian A form is

$$H^{(A)} = H_r + H_d^{(4)} + H_d^{(6)} + H_d^{(8)}, \tag{4.1}$$

$$H_r = 1/2(C+A)P^2 + [B - 1/2(C+A)](P_z^2 - b_o P_-^2), \tag{4.2}$$

$$H_d^{(4)} = -\Delta_J P^4 - \Delta_{JK} P^2 P_Z^2 - \Delta_K P_Z^4 - 2\delta_J P^2 P_-^2 - \delta_K (P_Z^2 P_-^2 + P_-^2 P_Z^2), \tag{4.3}$$

$$\begin{aligned} H_d^{(6)} = {} & H_J P^6 + H_{JK} P^4 P_Z^2 + H_{KJ} P^2 P_Z^4 + H_K P_Z^6 \\ & + 2\phi_J P^4 P_-^2 + \phi_{JK} P^2 (P_Z^2 P_-^2 + P_-^2 P_Z^2) \\ & + \phi_K (P_Z^4 P_-^2 + P_-^2 P_Z^4), \end{aligned} \tag{4.4}$$

$$H_d^{(8)} = L_J P^8 + L_{JJK} P^6 P_Z^2 + L_{JK} P^4 P_Z^4 + L_{KKJ} P^2 P_Z^6$$

$$+L_K P_Z^8 + 2l_J P^6 P_-^2 + l_{JK} P^4 (P_Z^2 P_-^2 + P^2 P_Z^2)$$

$$+l_{KJ} P^2 (P_Z^4 P_-^2 P_Z^4) + l_K (P_Z^6 P_-^2 + P_-^2 P_Z^6), \tag{4.5}$$

where Δ_J etc. are the quartic distortion coefficients; H_J and ϕ etc. are the sextic distortion coefficients: L_J etc. are the 8th order distortion coefficients; $b_o = \frac{(B_z - B_y)}{(2B_x - B_y - B_z)}$ is Wang's asymmetry parameter with $\kappa = \frac{-1}{b_o}$, and $P^2 = P_x^2 + P_y^2 + P_z^2$. Here, we have used the definition

$$P_-^2 = P_x^2 - P_y^2 \tag{4.6}$$

The S form of Watson's reduced centrifugal distortion Hamiltonian is

$$H^{(S)} = H_r + H_d^{(4)} + H_d^{(6)} + H_d^{(8)}, \tag{4.7}$$

$$H_r = 1/2(B+C)P^2 + [A - 1/2(B+C)](P_z^2 + 1/4(B-C)(P_+^2 + P_-^2), \tag{4.8}$$

$$H_d^{(4)} = -D_J P^4 - D_{JK} P^2 P_Z^2 - D_K P_Z^4 + d_1 P^2 (P_+^2 + P_-^2) + d_2 (P_+^4 + P_-^4), \tag{4.9}$$

$$H_d^{(6)} = H_J P^6 + H_{JK} P^4 P_Z^2 + H_{KJ} P^2 P_Z^4 + H_K P_Z^6$$

$$+h_1 P^4 (P_+^2 + P_-^2) + h_2 P^2 (P_+^4 + P_-^4)$$

$$+h_3 (P_+^6 + P_-^6), \tag{4.10}$$

$$H_d^{(8)} = L_J P^8 + L_{JJK} P^6 P_Z^2 + L_{JK} P^4 P_Z^4 + L_{KKJ} P^2 P_Z^6$$

$$+L_K P_Z^8 + l_1 P^6 (P_+^2 + P_-^2) + l_2 P^4 (P_+^4 + P_-^4)$$

$$+l_3 P^2 (P_+^6 + P_-^6) + l_4 (P_+^8 + P_-^8), \tag{4.11}$$

Hillman compared the A- (asymmetric) and S-reduced (symmetric) Watson Hamiltonians in the I^r and III^r representations and determined that the A-reduced, I^r representation provided the lowest rms deviation to the observed spectra, converged

the fastest, and was numerically more stable than the other combinations (29). The program that we used to fit the HNO_3 was obtained from Jet Propulsion Laboratory (JPL). The multi-purpose program; calfit was developed by Pickett of JPL (30). It can fit asymmetric rotors with up to nine interacting states. The nitric acid data set was fit to the A and S reduced Watson Hamiltionians, using the III^l representation. However, we did not come up with conclusive evidence as to which Hamiltionian provides the most stability, speed, and the lowest rms value.

A bootstrap assignment-analysis procedure was used. At each step lines were selected for measurement that provided a maximum of new independent information for the analysis, while having minimum risk of assignment error (3). This amounted to the selection of lines whose prediction uncertainties were small, usually on the order of several megahertz. This procedure was duplicated until several hundred lines of significant strength below $J = 60$ were measured with an uncertainty of 1 MHz or less.

The strongest features in the nitric acid spectrum are due to

$$\Delta J = 1$$

transitions that are quadruply degenerate. These transitions are of the form

$$J' - n(n, J' - 2n) \rightarrow J' - 1 - n(n, J' - 1 - 2n) \tag{4.12}$$

$$J' - n(n+1, J' - 2n) \rightarrow J' - 1 - n(n+1, J' - 1 - 2n) \tag{4.13}$$

$$J' - n(n, J' - 2n) \rightarrow J' - 1 - n(n+1, J' - 1 - 2n) \tag{4.14}$$

$$J' - n(n+1, J' - 2n) \rightarrow J' - 1 - n(n, J' - 1 - 2n) \tag{4.15}$$

where J' is the maximum J value for the branch and where $n = 0, 1, 2, ..$ These values occur in bands of lines which, in the near oblate asymmetric-rotor limit, are separated

by

$$A + B - 4C.$$

For vibrational states of nitric acid, this number is nearly zero and the bands are closely spaced. The spectra of the several states were initially assigned by using a broadband spectrometer, which made continuous scans of about 1 GHz centered on the frequencies of the strong ground state R-branch series. The spectra around the location of the band head being the most important. The different states then appear as families of equally-spaced lines that were identifiable on the basis of their relative strengths. As a result, the rotational spectra of several vibrational states were identified and assigned in a reasonably straightforward manner. The relative strengths of the absorption lines were used to correlate the different vibrational states with the several assigned spectra. For lines of reasonable strength, the intensity ratios agreed with expectations to about 10 percent (25).

In addition, the lower-order distortion constants are relatively constant among the vibrational states. Because of the extremely crowded nature of this spectrum and the large number of the states involved, we have made extensive use of the procedure in which observed lines are removed one at a time from the data set, the remaining lines were analyzed to predict the frequency of the removed line, and comparisons were then made between the predicted frequency, the calculated uncertainty in the predicted frequency, and the observed transition frequency. Although this procedure does not completely ensure against the inclusion of misassigned lines in the analyses of the several vibrational states, the procedure, combined with substantial redundancy of the data sets, does ensure that any possible misassignments will have no significant effect on the results, as explained by Crownover *et al.*(3)

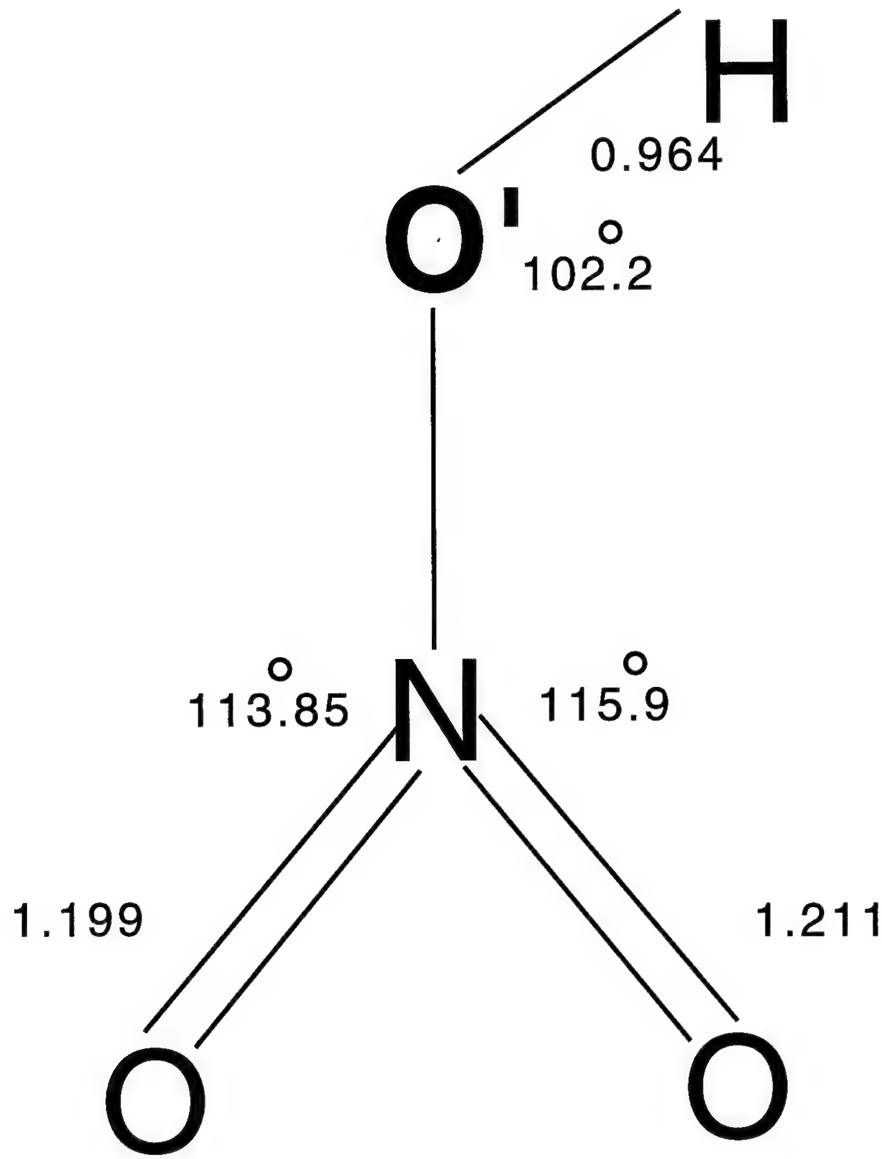


Figure 4.1: Structure ofNitric Acid

4.1 Results

The ν_8 vibrational state, which is derived from the NO_2 out-of-plane vibration, lies $762cm^{-1}$ above the ground state and results in transition strengths that are reduced by a factor of about 50.(25) Although the mm/submm spectrum of nitric acid is very crowded, previous analyses of the lower-lying vibrational states allowed us to eliminate the large proportion of stronger lines that did not belong to ν_8 and greatly simplified the assignment. The previously reported analysis of ν_8 assigned 215 new transitions. These covered the range from $J = 9$ to 46 and from $K_p = 0$ to 21. The rms deviation from the fit of the 215 lines was 0.066 MHz. The additional information from the FASSST spectra provided 265 newly measured lines. The spectral constants that result from the combine analysis of the data are shown in Table (5.2), along with the rms deviation of the fit, 0.082 MHz. Because of correlations among the constants, it is necessary to retain more digits in the spectral constants than indicated by the uncertainties, so that the spectrum can be accurately calculated from the constants.

The ν_7 vibrational state, which is derived from the ONO' bend, lies $579.0cm^{-1}$ above the ground state. We have previously reported an analysis of the ν_7 state which also used a phase locked, harmonic generation system (31). In that study about 140 rotational lines in the 100-600 GHz region were identified and fit to a Watson Hamiltonian with an rms deviation of 0.068 MHz (10). In the FASSST system, 510 lines were identified and measured in the 247-375 GHz region by Petkie 1996 (21). These were combined with earlier lines in a Watson analysis with an overall rms deviation of 0.081 KHz.

The ν_6 vibrational state, which is derived from the NO' stretching mode, is the third lowest lying, being centered $647cm^{-1}$ above the ground state. Previous

measurements of data produced 188 transitions spanning the region from 100-700 GHz (11). These transitions have been combined with the assigned transition from the FASST spectral scan. Over 320 lines have been identified and measured in the 240-375 GHz region. The combined rms deviation of the two sources is 0.090631 MHz. The spectral constants that result from the combine analysis of the data are shown in Table(5.8).

CHAPTER 5

Summary

In this report we have measured the FASSST spectra data from 245 to 370 GHz which has been signaled average as opposed to the one scan taken previously. The analyses of the vibrational states of nitric acid were evaluated by using Watson's reduced centrifugal distortion Hamiltonian in both its A form and S form. The results for ν_7 and ν_8 had comparable rms values as expected; however, the ν_6 analyses did not reproduced the same results. At a quick glance it would seem that the S reduced form is much better than the A reduced form. The difference between the two Hamiltonian's rms values is about 34 KHz. The A reduced and the S reduced Hamiltionian both use commutation relations to constrain the number of coefficients that exist in their higher ordered terms. This reduction results in various P^6 coefficients being folded into other coefficients. How the 6th order distortion coefficients introduces itself into the lower degree terms in the A reduced form and S reduced form differ slightly. The mixing of the P^4 and P^6 terms in the S reduced Watson Hamiltionian does a better job of converging the analysis than the mixing of the A reduced form. It seems more equipped to handle the important higher order effects of the molecule; therefore, the S representation seems to be better suited for the ν_6 analysis. Although, at some limit you would expect the different linear combinations

of both the A and S reduced Watson Hamiltionian parameters to yield the same rms values. However, after further investigation we see that not all the constants in the S reduced form are well determined. The sextic distortion coefficients of the A form are better determined then those from the S form.

An average of 450 transitions was observed for each vibrational state using the FASSST system. These lines are consisted with the theoretical and experimental values of previous experiments using a broadband spectrometer. The analysis of ν_6, ν_7 and ν_8 is part of a larger project that will compile a complete study of all the excited states of nitric acid in Table(3.1). However, it will include $2\nu_9$ and $3\nu_9$, which are perturbed states of HNO_3, but exclude ν_1 because of its distance from the ground state. The FASSST system will be used to acquire all necessary spectra.

Table 5.1: Observed and calculated microwave transition frequencies for the $n = 8$ vibrational state of nitric acid .

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
7	5	3	$\leftarrow$	6	5	2	141377.470	9	0.101
7	5	2	$\leftarrow$	6	5	1	155636.044	56	0.101
8	3	5	$\leftarrow$	7	3	4	143830.360	-13	0.100
9	1	8	$\leftarrow$	8	1	7	131352.490	-7	0.100
9	4	6	$\leftarrow$	8	4	5	156271.044	-9	0.100
10	0	10	$\leftarrow$	9	0	9	131430.908	-107	0.100
10	1	9	$\leftarrow$	9	1	8	143871.240	-109	0.100
10	2	8	$\leftarrow$	9	2	7	156315.927	-5	0.100
10	10	1	$\leftarrow$	9	9	0	257175.014	100	0.101
10	10	0	$\leftarrow$	9	9	1	257448.600	-22	0.101
11	0	11	$\leftarrow$	10	0	10	143950.599	6	0.101
11	1	10	$\leftarrow$	10	1	9	156390.015	23	0.101
11	2	9	$\leftarrow$	10	2	8	168832.051	-6	0.100
11	4	7	$\leftarrow$	10	4	6	193767.578	-32	0.100
11	5	7	$\leftarrow$	10	5	6	193764.941	-60	0.100
12	0	12	$\leftarrow$	11	0	11	156469.736	-64	0.100
12	1	11	$\leftarrow$	11	1	10	168908.302	-17	0.100
12	2	10	$\leftarrow$	11	2	9	181348.486	54	0.100
12	6	7	$\leftarrow$	11	6	6	218773.640	60	0.100
12	10	3	$\leftarrow$	11	10	2	254807.557	41	0.101
12	11	2	$\leftarrow$	11	11	1	252759.725	-11	0.101
13	0	13	$\leftarrow$	12	0	12	168988.574	-29	0.100
13	2	11	$\leftarrow$	12	2	10	193864.697	-35	0.100
13	4	9	$\leftarrow$	12	4	8	218764.086	-78	0.100
13	5	8	$\leftarrow$	12	5	7	231252.685	58	0.100
13	7	6	$\leftarrow$	12	7	5	256840.649	-50	0.101
13	8	5	$\leftarrow$	12	8	4	272070.832	-65	0.101
13	9	4	$\leftarrow$	12	9	3	287812.150	205	0.100
13	10	4	$\leftarrow$	12	10	3	275348.295	-65	0.101
13	10	3	$\leftarrow$	12	10	2	290177.462	-105	0.100
13	1	12	$\leftarrow$	13	1	13	155453.693	79	0.101
14	0	14	$\leftarrow$	13	0	13	181506.884	-84	0.100
14	1	13	$\leftarrow$	13	1	12	193943.701	-63	0.100
14	2	12	$\leftarrow$	13	2	11	206380.850	77	0.100
14	3	11	$\leftarrow$	13	3	10	218820.996	-21	0.100
14	4	10	$\leftarrow$	13	4	9	231270.458	27	0.100
14	6	8	$\leftarrow$	13	6	7	256262.987	-135	0.100

Table 5.1: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
14	7	8	←	13	7	7	256260.155	-251	0.100
14	9	6	←	13	9	5	281411.519	13	0.100
14	3	11	←	14	3	12	142855.181	26	0.101
14	1	13	←	14	1	14	167890.430	21	0.101
15	0	15	←	14	0	14	194024.853	-9	0.100
15	1	14	←	14	1	13	206460.742	-37	0.100
15	3	12	←	14	3	11	231334.243	21	0.100
15	4	11	←	14	4	10	243778.655	61	0.100
15	5	10	←	14	5	9	256238.196	24	0.100
15	8	7	←	14	8	6	294119.995	103	0.100
15	10	6	←	14	10	5	306372.247	75	0.100
15	2	13	←	15	2	14	167816.145	56	0.101
16	0	16	←	15	0	15	206542.216	-36	0.100
16	1	15	←	15	1	14	218977.197	-69	0.100
16	2	14	←	15	2	13	231411.620	3	0.100
16	4	12	←	15	4	11	256287.750	77	0.100
16	5	11	←	15	5	10	268739.099	-23	0.100
16	4	13	←	15	4	12	243847.323	52	0.105
16	6	10	←	15	6	9	281213.808	16	0.100
16	8	8	←	15	8	7	306375.647	19	0.100
16	14	2	←	15	12	3	447382.455	-80	0.100
16	6	10	←	16	6	11	130009.397	24	0.101
16	3	13	←	16	3	14	167728.633	32	0.101
17	0	17	←	16	0	16	219059.033	-71	0.100
17	1	16	←	16	1	15	231493.208	20	0.100
17	2	15	←	16	2	14	243926.233	-30	0.100
17	3	14	←	16	3	13	256359.912	-69	0.100
17	4	13	←	16	4	12	268797.053	-38	0.100
17	5	12	←	16	5	11	281242.366	-4	0.100
17	6	11	←	16	6	10	293704.638	111	0.100
17	9	8	←	16	9	7	331502.247	86	0.100
17	10	8	←	16	10	7	331449.968	-138	0.100
17	11	7	←	16	11	6	344197.593	176	0.100
17	7	10	←	17	7	11	129817.654	34	0.101
17	6	11	←	17	6	12	142471.550	21	0.101
18	2	16	←	17	2	15	256440.270	-45	0.100
18	3	15	←	17	3	14	268872.213	-13	0.100
18	3	16	←	17	3	15	256440.255	-60	0.100
18	4	14	←	17	4	13	281306.478	-8	0.100

Table 5.1: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
18	5	13	←	17	5	12	293746.826	-8	0.100
18	7	11	←	17	7	10	318676.966	-40	0.100
18	9	9	←	17	9	8	343822.705	88	0.100
18	10	9	←	17	10	8	343816.210	192	0.100
18	17	1	←	17	16	2	459868.244	-22	0.100
18	17	2	←	17	16	1	459813.127	2	0.100
18	2	17	←	17	2	16	244008.451	-54	0.105
18	7	11	←	18	7	12	142294.880	5	0.101
19	1	18	←	18	1	17	256523.095	-89	0.100
19	2	17	←	18	2	16	268953.776	51	0.100
19	3	16	←	18	3	15	281383.876	-31	0.100
19	7	12	←	18	8	11	331161.394	-62	0.105
19	4	15	←	18	4	14	293815.576	-38	0.100
19	6	13	←	18	6	12	318697.568	-20	0.100
19	10	9	←	18	10	8	368917.197	29	0.100
19	11	8	←	18	11	7	382005.469	34	0.100
19	11	9	←	18	11	8	368900.579	17	0.100
19	12	8	←	18	12	7	381748.014	95	0.100
19	1	19	←	18	1	18	244091.119	51	0.105
19	17	2	←	19	15	5	142666.830	65	0.101
20	1	19	←	20	1	20	242491.832	96	0.104
20	8	12	←	19	9	11	356129.385	40	0.105
20	8	13	←	19	8	12	343650.513	-84	0.105
20	5	16	←	19	4	15	306324.353	47	0.105
20	0	20	←	19	0	19	256606.005	-108	0.100
20	1	19	←	19	1	18	269037.255	63	0.100
20	1	20	←	19	1	19	256606.176	62	0.100
20	2	18	←	19	2	17	281466.431	-13	0.100
20	5	15	←	19	5	14	318757.007	32	0.100
20	6	14	←	19	6	13	331196.837	-59	0.100
20	11	9	←	19	11	8	394060.819	-91	0.100
20	17	3	←	20	15	6	143035.195	-5	0.101
21	8	14	←	20	8	13	356142.508	-76	0.105
21	7	15	←	20	7	14	343696.898	-43	0.105
21	1	20	←	20	1	19	281550.390	-101	0.100
21	2	19	←	20	2	18	293978.454	16	0.100
21	4	17	←	20	4	16	318832.433	3	0.100
21	5	16	←	20	5	15	331261.971	52	0.100
21	8	13	←	20	8	12	368607.180	-86	0.100

Table 5.1: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
21	9	12	←	20	9	11	381105.625	98	0.100
21	14	7	←	20	14	6	450507.963	-20	0.100
21	15	7	←	20	15	6	443872.344	-7	0.100
21	16	5	←	20	16	4	470529.270	93	0.100
21	16	6	←	20	16	5	450926.531	48	0.100
21	17	4	←	20	17	3	457842.046	37	0.100
21	17	5	←	20	17	4	451191.356	54	0.100
21	18	3	←	20	18	2	448296.276	111	0.100
21	18	4	←	20	18	3	447387.561	113	0.100
21	19	2	←	20	19	1	443214.733	100	0.100
21	1	20	←	21	1	21	254921.643	-92	0.101
22	3	19	←	22	3	20	242304.935	-45	0.104
22	6	16	←	21	6	15	356197.217	-16	0.105
22	0	22	←	21	0	21	281634.159	-11	0.100
22	1	21	←	21	1	20	294062.988	-62	0.100
22	4	18	←	21	4	17	331339.857	-31	0.100
22	5	17	←	21	5	16	343766.438	-28	0.100
22	10	12	←	21	10	11	406092.441	70	0.100
22	13	9	←	21	13	8	444570.778	80	0.100
22	14	8	←	21	14	7	459130.123	83	0.100
22	14	9	←	21	14	8	444385.264	-19	0.100
22	15	7	←	21	15	6	477988.882	68	0.100
22	15	8	←	21	15	7	457292.928	30	0.100
22	16	7	←	21	16	6	468253.552	40	0.100
22	17	6	←	21	17	5	473581.978	-8	0.100
22	18	4	←	21	18	3	476895.452	7	0.100
22	18	5	←	21	18	4	472340.032	52	0.100
22	20	2	←	21	20	1	463852.096	-5	0.100
22	20	3	←	21	20	2	463817.479	-11	0.100
22	2	20	←	22	2	21	254829.744	68	0.101
22	19	4	←	22	17	5	130231.509	75	0.101
22	1	21	←	22	1	22	267350.458	-157	0.101
23	4	19	←	23	4	20	242196.665	-78	0.104
23	6	18	←	22	5	17	356270.433	-25	0.105
23	0	23	←	22	0	22	294147.054	-62	0.100
23	2	21	←	22	2	20	319000.142	57	0.100
23	3	20	←	22	3	19	331423.541	-107	0.100
23	4	19	←	22	4	18	343846.711	109	0.100
23	6	17	←	22	6	16	368697.386	-39	0.100

Table 5.1: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
23	9	14	←	22	9	13	406040.328	11	0.100
23	13	10	←	22	13	9	456600.703	-69	0.100
23	14	9	←	22	14	8	469997.771	-20	0.100
23	14	10	←	22	14	9	456571.990	-98	0.100
23	15	9	←	22	15	8	469623.976	28	0.100
23	16	8	←	22	16	7	482371.676	112	0.100
23	19	5	←	22	19	4	493256.693	-7	0.100
23	20	3	←	22	20	2	488972.598	-47	0.100
23	20	4	←	22	20	3	488662.546	-79	0.100
23	21	2	←	22	21	1	484497.938	-111	0.100
23	21	3	←	22	21	2	484479.657	60	0.100
23	3	20	←	23	3	21	254728.635	90	0.101
23	1	22	←	23	1	23	279778.193	-142	0.101
23	2	21	←	23	2	22	267254.691	-233	0.101
24	1	23	←	23	1	22	319085.800	-15	0.100
24	2	22	←	23	2	21	331509.618	-47	0.100
24	3	21	←	23	3	20	343931.578	4	0.100
24	5	19	←	23	5	18	368773.701	-70	0.100
24	6	18	←	23	6	17	381197.301	32	0.100
24	11	13	←	23	11	12	443516.076	10	0.100
24	14	11	←	23	14	10	468826.338	-33	0.100
24	2	22	←	24	2	23	279678.790	15	0.101
24	5	20	←	24	3	21	254617.719	48	0.101
24	3	21	←	24	3	22	267150.377	-74	0.101
25	0	25	←	24	0	24	319170.731	47	0.100
25	1	24	←	24	1	23	331595.970	15	0.100
25	3	22	←	24	4	21	356438.512	-92	0.105
25	2	23	←	24	2	22	344018.400	28	0.100
25	4	21	←	24	4	20	368857.505	-20	0.100
25	10	15	←	24	10	14	443459.055	42	0.100
25	12	13	←	24	12	12	468505.238	-21	0.100
25	5	20	←	25	5	21	254496.354	4	0.101
25	1	24	←	25	1	25	304630.201	78	0.101
25	4	21	←	25	4	22	267036.533	-57	0.101
25	3	22	←	25	3	23	279570.629	-55	0.101
25	2	23	←	25	2	24	292101.183	-9	0.101
26	0	26	←	25	1	25	331681.269	29	0.105
26	4	23	←	25	4	22	368944.729	25	0.105
26	1	25	←	25	1	24	344105.191	-29	0.100

Table 5.1: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
26	6	20	←	25	6	19	406195.161	-30	0.100
26	10	16	←	25	10	15	455928.005	83	0.100
26	11	15	←	25	11	14	468405.077	31	0.100
26	6	20	←	26	6	21	254363.789	-51	0.101
26	1	25	←	26	1	26	317054.059	-45	0.101
26	3	24	←	26	1	25	304522.166	26	0.101
26	4	22	←	26	4	23	279453.499	-13	0.101
26	5	21	←	26	5	22	266912.866	161	0.101
26	3	23	←	26	3	24	291989.135	-85	0.101
27	0	27	←	26	0	26	344190.937	4	0.100
27	2	25	←	26	2	24	369033.039	19	0.100
27	8	19	←	26	8	18	443530.217	175	0.100
27	10	17	←	26	10	16	468400.014	11	0.100
27	11	16	←	26	11	15	480861.882	84	0.100
27	4	24	←	27	2	25	304405.974	-58	0.101
27	1	26	←	27	1	27	329476.846	93	0.101
27	2	25	←	27	2	26	316941.612	34	0.101
27	7	20	←	27	7	21	254219.341	-25	0.101
27	6	21	←	27	6	22	266778.140	14	0.101
27	4	23	←	27	4	24	291868.442	11	0.101
28	0	28	←	28	2	27	341898.064	40	0.100
28	9	20	←	28	7	21	254062.048	-62	0.101
28	4	24	←	28	4	25	304281.222	-114	0.101
28	7	21	←	28	7	22	266632.292	139	0.101
28	6	22	←	28	6	23	279189.838	261	0.101
28	5	23	←	28	5	24	291738.438	142	0.101
28	4	25	←	28	2	26	316820.930	-160	0.101
28	2	26	←	28	2	27	329359.468	0	0.101
28	1	27	←	27	1	26	369121.034	30	0.100
28	2	26	←	27	2	25	381538.927	34	0.100
28	4	24	←	27	4	23	406366.809	-47	0.100
28	7	21	←	27	7	20	443602.718	7	0.100
28	8	20	←	27	8	19	456018.958	76	0.100
28	10	18	←	27	10	17	480874.145	37	0.100
29	0	29	←	28	0	28	369207.693	88	0.100
29	1	28	←	29	3	27	341775.937	170	0.100
29	6	23	←	28	6	22	443685.863	4	0.100
29	7	22	←	28	7	21	456095.265	-15	0.100
29	8	21	←	28	8	20	468507.232	11	0.100

Table 5.1: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
29	11	18	←	28	11	17	505787.970	-42	0.100
29	9	20	←	29	9	21	253891.233	14	0.101
29	5	24	←	29	5	25	304147.545	-23	0.101
29	1	28	←	29	1	29	354318.035	162	0.101
29	5	25	←	29	3	26	316692.191	-22	0.101
29	3	26	←	29	3	27	329234.334	-27	0.101
29	7	22	←	29	7	23	279041.515	-58	0.101
29	6	23	←	29	6	24	291598.145	-115	0.101
29	8	21	←	29	8	22	266473.999	-52	0.101
30	0	30	←	29	0	29	381714.568	49	0.100
30	2	28	←	30	4	27	341645.801	-9	0.100
30	5	25	←	29	5	24	443774.777	0	0.100
30	8	22	←	29	8	21	480994.901	31	0.100
30	7	23	←	29	7	22	468586.829	-86	0.100
30	9	21	←	29	9	20	493406.689	-17	0.100
30	11	20	←	30	9	21	253705.713	-77	0.101
30	7	24	←	30	5	25	304004.246	24	0.101
30	2	28	←	30	2	29	354190.382	-52	0.101
30	5	25	←	30	5	26	316554.540	37	0.101
30	9	21	←	30	9	22	266303.068	12	0.101
30	8	22	←	30	8	23	278882.057	51	0.101
30	7	23	←	30	7	24	291447.566	-183	0.101
31	1	30	←	30	1	29	406637.337	25	0.100
31	3	28	←	31	5	27	341507.832	43	0.100
31	4	27	←	30	4	26	443866.628	-18	0.100
31	5	26	←	30	5	25	456271.133	-100	0.100
31	6	25	←	30	6	24	468674.518	15	0.100
31	7	24	←	30	7	23	481077.522	0	0.100
31	8	23	←	30	8	22	493481.618	-58	0.100
31	9	22	←	30	9	21	505888.767	-33	0.100
31	7	24	←	31	7	25	303850.907	138	0.101
31	11	20	←	31	11	21	253504.715	-170	0.101
31	5	26	←	31	5	27	328959.014	-75	0.101
31	6	25	←	31	6	26	316407.563	72	0.101
31	9	22	←	31	9	23	278710.090	-89	0.101
31	8	23	←	31	8	24	291286.167	6	0.101
31	10	21	←	31	10	22	266118.359	0	0.101
31	4	28	←	31	2	29	354055.510	108	0.101
32	0	32	←	31	0	31	406725.337	-1	0.100

Table 5.1: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
32	3	29	←	31	3	28	443959.600	-24	0.100
32	4	28	←	31	4	27	456364.167	-102	0.100
32	4	28	←	32	6	27	341361.184	-135	0.100
32	9	24	←	32	7	25	303686.668	8	0.101
32	7	26	←	32	5	27	328808.010	-73	0.101
32	7	25	←	32	7	26	316250.740	45	0.101
32	11	21	←	32	11	22	265919.034	-88	0.101
32	10	22	←	32	10	23	278525.370	0	0.101
32	9	23	←	32	9	24	291112.791	-72	0.101
32	4	28	←	32	4	29	353912.509	75	0.101
32	5	27	←	31	5	26	468766.428	-71	0.100
32	6	26	←	31	6	25	481167.084	-7	0.100
33	2	31	←	32	2	30	444052.458	50	0.100
33	3	30	←	32	3	29	456458.145	-22	0.100
33	5	28	←	33	7	27	341206.033	27	0.100
33	14	20	←	33	12	21	253052.777	134	0.101
33	7	26	←	33	7	27	328647.508	-65	0.101
33	9	24	←	33	9	25	303511.393	73	0.101
33	8	25	←	33	8	26	316083.536	-74	0.101
33	11	22	←	33	11	23	278326.774	-48	0.101
33	10	23	←	33	10	24	290927.341	137	0.101
33	12	21	←	33	12	22	265704.378	-84	0.101
33	5	28	←	33	5	29	353761.101	-73	0.101
33	6	27	←	32	6	26	493658.453	-1	0.100
34	1	33	←	33	1	32	444143.990	-5	0.100
34	2	32	←	33	2	31	456551.656	-51	0.100
34	3	31	←	33	3	30	468955.428	-63	0.100
34	9	25	←	34	9	26	315905.481	-231	0.101
34	8	27	←	34	6	28	341041.535	100	0.101
34	3	31	←	34	5	30	378715.161	-120	0.100
34	10	24	←	34	10	25	303324.009	-144	0.101
34	13	21	←	34	13	22	265473.503	46	0.101
34	11	23	←	34	11	24	290728.644	150	0.101
34	12	22	←	34	12	23	278113.859	116	0.101
34	14	20	←	34	14	21	252799.229	51	0.101
34	6	28	←	34	6	29	353601.272	15	0.101
35	0	35	←	34	0	34	444233.557	-7	0.100
35	1	34	←	34	1	33	456644.007	75	0.100
35	2	33	←	34	2	32	469049.801	5	0.100

Table 5.1: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
35	4	31	←	34	4	30	493849.601	-97	0.100
35	4	31	←	35	6	30	378553.650	-21	0.100
35	13	22	←	35	13	23	277885.486	181	0.101
35	9	26	←	35	9	27	328296.023	-146	0.101
35	10	25	←	35	10	26	315716.547	92	0.101
35	11	24	←	35	11	25	303124.292	-244	0.101
35	12	23	←	35	12	24	290515.936	-85	0.101
35	14	21	←	35	14	22	265225.111	-26	0.101
35	7	28	←	35	9	27	340867.147	-30	0.100
35	15	20	←	35	15	21	252526.057	80	0.101
36	1	35	←	35	1	34	469142.689	21	0.100
36	2	34	←	35	2	33	481546.584	-53	0.100
36	3	33	←	35	3	32	493946.320	-27	0.100
36	5	31	←	36	7	30	378383.668	-36	0.100
36	11	25	←	36	11	26	315515.272	3	0.101
36	12	24	←	36	12	25	302911.827	5	0.101
36	15	21	←	36	15	22	264958.337	-154	0.101
36	14	22	←	36	14	23	277640.487	-157	0.101
36	13	23	←	36	13	24	290289.058	18	0.101
36	8	28	←	36	10	27	340682.793	3	0.100
36	16	20	←	36	16	21	252231.794	-43	0.101
36	11	26	←	36	9	27	328104.308	16	0.101
36	8	28	←	36	8	29	353253.877	-20	0.101
37	0	37	←	36	0	36	469233.402	67	0.100
37	1	36	←	36	1	35	481640.115	-56	0.100
37	2	35	←	36	2	34	494042.107	-95	0.100
37	11	26	←	37	11	27	327900.982	41	0.101
37	12	25	←	37	12	26	315301.471	-90	0.101
37	13	24	←	37	13	25	302685.351	18	0.101
37	9	28	←	37	11	27	340487.888	79	0.100
37	9	28	←	37	9	29	353065.587	-60	0.101
37	15	22	←	37	15	23	277378.854	-1	0.101
37	14	23	←	37	14	24	290046.709	-61	0.101
37	16	21	←	37	16	22	264672.463	7	0.101
37	17	20	←	37	17	21	251915.463	-28	0.101
38	0	38	←	37	0	37	481731.519	111	0.100
38	1	37	←	37	1	36	494136.404	-5	0.100
38	13	26	←	38	11	27	327685.618	44	0.101
38	14	24	←	38	14	25	302444.264	-100	0.101

Table 5.1: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
38	13	25	←	38	13	26	315074.654	-65	0.101
38	7	31	←	38	9	30	378017.405	42	0.100
38	10	28	←	38	10	29	352867.189	70	0.101
38	16	22	←	38	16	23	277098.824	-168	0.101
38	17	21	←	38	17	22	264365.895	-17	0.101
38	18	20	←	38	18	21	251575.588	-18	0.101
38	15	23	←	38	15	24	289788.303	-99	0.101
39	1	38	←	38	1	37	506631.408	59	0.100
39	15	24	←	39	15	25	302188.086	-97	0.101
39	12	27	←	39	12	28	340064.241	114	0.101
39	14	25	←	39	14	26	314834.185	84	0.101
39	13	26	←	39	13	27	327457.694	64	0.101
39	8	31	←	39	10	30	377820.404	116	0.100
39	19	20	←	39	19	21	251210.852	78	0.101
39	11	28	←	39	11	29	352657.852	-15	0.101
39	18	21	←	39	18	22	264037.762	69	0.101
39	16	23	←	39	16	24	289513.107	21	0.101
40	0	40	←	39	0	39	506723.766	0	0.100
40	1	39	←	39	1	38	519125.009	51	0.100
40	16	24	←	40	16	25	301916.045	20	0.101
40	15	25	←	40	15	26	314579.128	88	0.101
40	12	28	←	40	12	29	352437.419	-14	0.101
40	14	26	←	40	14	27	327216.503	-19	0.101
40	20	20	←	40	20	21	250819.558	50	0.101
40	18	22	←	40	18	23	276481.012	-17	0.101
40	17	23	←	40	17	24	289219.908	-24	0.101
40	19	21	←	40	19	22	263686.475	-85	0.101
40	13	27	←	40	13	28	339834.377	-33	0.101
41	0	41	←	40	0	40	519217.987	-1	0.100
41	17	24	←	41	17	25	301626.942	-147	0.101
41	16	25	←	41	16	26	314308.888	47	0.101
41	13	28	←	41	13	29	352205.254	-86	0.101
41	21	20	←	41	21	21	250400.168	-66	0.101
41	20	21	←	41	20	22	263311.184	-35	0.101
41	19	22	←	41	19	23	276140.723	-78	0.101
41	18	23	←	41	18	24	288908.049	31	0.101
41	14	27	←	41	14	28	339592.094	26	0.101
42	5	37	←	42	7	36	452665.134	19	0.100
42	18	24	←	42	18	25	301320.441	-102	0.101

Table 5.1: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
42	16	26	←	42	16	27	326692.400	39	0.101
42	17	25	←	42	17	26	314022.815	32	0.101
42	14	28	←	42	14	29	351961.222	128	0.101
42	22	20	←	42	22	21	249951.280	-7	0.101
42	21	21	←	42	21	22	262910.179	-121	0.101
42	20	22	←	42	20	23	275778.369	133	0.101
42	19	23	←	42	19	24	288576.460	91	0.101
42	15	27	←	42	15	28	339336.426	-116	0.101
43	19	24	←	43	19	25	300995.661	143	0.101
43	17	26	←	43	17	27	326408.133	118	0.101
43	18	25	←	43	18	26	313720.046	-64	0.101
43	15	28	←	43	15	29	351704.177	-3	0.101
43	21	22	←	43	21	23	275392.291	161	0.101
43	22	21	←	43	22	22	262482.397	35	0.101
43	23	20	←	43	23	21	249471.012	112	0.101
43	20	23	←	43	20	24	288224.015	44	0.101
43	16	27	←	43	16	28	339067.379	125	0.101
44	24	20	←	44	24	21	248957.201	13	0.104
44	19	25	←	44	19	26	313399.776	-264	0.101
44	6	38	←	44	8	37	464814.343	-27	0.100
44	16	28	←	44	16	29	351434.071	2	0.101
44	23	21	←	44	23	22	262026.040	165	0.101
44	7	37	←	44	9	36	452228.372	79	0.100
44	22	22	←	44	22	23	274981.190	-29	0.101
44	21	23	←	44	21	24	287849.772	13	0.101
44	20	24	←	44	20	25	300651.134	31	0.101
44	17	27	←	44	17	28	338783.488	-113	0.101
44	19	26	←	44	17	27	326107.817	-106	0.101
45	26	19	←	45	26	20	235109.616	-30	0.104
45	25	20	←	45	25	21	248408.178	31	0.104
45	20	25	←	45	20	26	313061.752	0	0.101
45	8	37	←	45	10	36	451997.265	70	0.100
45	17	28	←	45	17	29	351150.172	-34	0.101
45	24	21	←	45	24	22	261539.034	-189	0.101
45	19	26	←	45	19	27	325791.337	-36	0.101
45	24	22	←	45	22	23	274544.145	-27	0.101
45	21	24	←	45	21	25	300286.337	-9	0.101
45	22	23	←	45	22	24	287452.626	11	0.101
45	18	27	←	45	18	28	338484.954	-6	0.101

Table 5.1: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
46	25	21	←	46	25	22	261020.603	-91	0.101
46	21	25	←	46	21	26	312704.387	-6	0.101
46	20	26	←	46	20	27	325457.587	-36	0.101
46	25	22	←	46	23	23	274079.527	-57	0.101
46	18	28	←	46	18	29	350851.848	-172	0.101
46	8	38	←	46	10	37	464347.390	48	0.100
46	23	23	←	46	23	24	287031.574	208	0.101
46	22	24	←	46	22	25	299900.469	213	0.101
46	19	27	←	46	19	28	338170.812	130	0.101
47	27	20	←	47	27	21	247195.428	70	0.104
47	22	25	←	47	22	26	312327.130	59	0.101
47	22	26	←	47	20	27	325105.921	20	0.101
47	25	22	←	47	25	23	273585.905	-66	0.101
47	26	21	←	47	26	22	260468.258	-207	0.101
47	23	24	←	47	23	25	299491.863	76	0.101
47	24	23	←	47	24	24	286584.858	80	0.101
47	20	27	←	47	20	28	337840.036	-54	0.101
48	28	20	←	48	28	21	246526.902	50	0.104
48	23	25	←	48	23	26	311928.888	37	0.101
48	21	27	←	48	21	28	337492.511	27	0.101
48	22	26	←	48	22	27	324735.503	103	0.101
48	27	21	←	48	27	22	259880.483	-113	0.101
48	26	22	←	48	26	23	273061.741	-20	0.101
48	20	28	←	48	20	29	350210.312	34	0.101
48	25	23	←	48	25	24	286111.627	75	0.101
48	24	24	←	48	24	25	299059.724	-122	0.101
49	29	20	←	49	29	21	245813.648	185	0.104
49	25	24	←	49	25	25	298603.219	-68	0.101
49	22	27	←	49	22	28	337127.005	-125	0.101
49	27	22	←	49	27	23	272505.442	150	0.101
49	24	26	←	49	22	27	324345.491	211	0.101
49	26	23	←	49	26	24	285610.299	-18	0.101
49	28	21	←	49	28	22	259254.867	-149	0.101
49	24	25	←	49	24	26	311508.571	-185	0.101
50	30	20	←	50	30	21	245052.133	-192	0.104
50	27	23	←	50	27	24	285079.690	59	0.101
50	24	27	←	50	22	28	336743.179	-91	0.101
50	29	22	←	50	27	23	271915.052	259	0.101
50	26	24	←	50	26	25	298120.854	-49	0.101

Table 5.1: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
51	31	20	←	51	31	21	244240.369	36	0.104
51	29	22	←	51	29	23	271288.186	-198	0.101
51	28	23	←	51	28	24	284518.130	169	0.101
51	27	24	←	51	27	25	297611.698	271	0.101
51	23	28	←	51	23	29	349124.429	-178	0.101
51	30	21	←	51	30	22	257881.627	-75	0.101
52	24	28	←	52	24	29	348727.258	101	0.101
52	30	22	←	52	30	23	270623.979	-81	0.101
52	28	24	←	52	28	25	297073.553	33	0.101
52	30	23	←	52	28	24	283923.651	-38	0.101
52	31	21	←	52	31	22	257129.184	146	0.101
53	29	24	←	53	29	25	296505.665	-105	0.101
53	32	21	←	53	32	22	256328.861	102	0.101
54	32	23	←	54	30	24	282630.244	-113	0.101
55	32	23	←	55	32	24	281927.459	-63	0.101

Table 5.2: Rotational Constants of ν_8 in the S reduced Watson Hamiltonian.

Results of Analysis ν_8 (MHz) S

Constants	Value	σ
A	12998.0287	0.00158
B	12005.5156	0.00130
C	6260.8157	0.00068
Δ_J	-0.014690	0.00000143
Δ_{JK}	0.023248	0.00000171
Δ_K	-0.009902	0.00000122
δ_1	-0.00124	0.00000173
δ_2	0.00036	0.00000162
H_J x E-07	0.2084	0.0081
H_{JJK} x E-06	-0.6400	0.0158
H_{JKK} x E-06	0.4236	0.021
H_K x E-06	0.052	0.125
h_1 x E-08	0.294	0.195
h_2 x E-07	-0.503	0.337
h_3 x E-06	0.8	0.6
rms	0.082533	

Table 5.3: Rotational Constants of ν_8 in the A reduced Watson Hamiltonian.

Results of Analysis ν_8 (MHz) A		
Constants	Value	σ
A	12998.0623	0.00174
B	12005.4781	0.00132
C	6260.8188	0.00071
Δ_J	-0.013980	0.00000175
Δ_{JK}	0.01899	0.0000065
Δ_K	-0.006354	0.0000056
δ_J	-0.00124	0.00000152
δ_K	0.01786	0.0000290
H_J x E-07	0.2536	0.0211
H_{JK} x E-06	-0.1475	0.0161
H_{KJ} x E-06	0.26089	0.02852
H_K x E-06	-0.13903	0.0173
ϕ_J x E-08	-0.209	0.056
ϕ_{JK} x E-07	-0.7504	0.5687
ϕ_K x E-06	0.1984	0.0658
rms	0.082352	

Table 5.4: Observed and calculated microwave transition frequencies for the $n = 7$ vibrational state of nitric acid .

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
5	5	0	←	4	4	1	130293.756	85	0.101
8	2	6	←	7	3	5	130957.665	-15	0.100
8	3	6	←	7	3	5	130957.665	-104	0.100
8	2	6	←	7	2	5	130959.130	111	0.100
8	3	6	←	7	2	5	130959.130	23	0.100
8	3	5	←	7	3	4	143728.955	55	0.100
8	5	4	←	7	5	3	156051.636	25	0.101
9	1	8	←	8	1	7	130660.288	35	0.101
9	2	7	←	8	3	6	143354.443	39	0.100
9	2	7	←	8	2	6	143354.443	-49	0.100
9	3	7	←	8	3	6	143354.443	33	0.100
9	3	7	←	8	2	6	143354.443	-54	0.100
9	3	6	←	8	3	5	156073.583	29	0.100
9	4	6	←	8	4	5	156068.212	-35	0.100
10	1	9	←	9	1	8	143061.578	8	0.100
10	2	8	←	9	2	7	155752.490	-17	0.100
10	4	6	←	9	4	5	181212.939	32	0.100
10	6	5	←	9	6	4	193893.017	66	0.100
10	8	2	←	9	6	3	271562.005	-55	0.101
11	0	11	←	10	0	10	142776.260	20	0.101
11	1	10	←	10	1	9	155462.856	12	0.101
11	3	9	←	10	3	8	168151.455	39	0.100
11	3	8	←	10	3	7	180848.486	-32	0.100
11	4	7	←	10	4	6	193571.826	182	0.100
11	5	7	←	10	4	6	193571.826	45	0.100
11	5	6	←	10	5	5	206393.935	21	0.100
11	8	3	←	10	8	2	247597.744	14	0.100
11	9	2	←	10	9	1	244305.611	51	0.100
12	2	10	←	11	2	9	180550.703	26	0.100
12	3	9	←	11	3	8	193242.919	-63	0.100
12	4	8	←	11	5	7	205951.455	68	0.100
12	4	8	←	11	4	7	205951.455	-67	0.100
12	5	8	←	11	5	7	205951.455	59	0.100
12	5	8	←	11	4	7	205951.455	-77	0.100
12	6	6	←	11	6	5	231642.842	-3	0.100
12	7	6	←	11	7	5	231507.226	108	0.100
12	7	5	←	11	7	4	245745.120	-15	0.100

Table 5.4: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
12	9	3	←	11	9	2	270925.443	-88	0.100
12	10	3	←	11	10	2	256962.852	6	0.100
12	10	2	←	11	10	1	264418.941	-61	0.100
12	11	1	←	11	11	0	256142.082	24	0.101
12	11	1	←	11	9	2	338621.038	-46	0.100
13	1	12	←	12	1	11	180264.990	4	0.100
13	3	10	←	12	3	9	205638.818	15	0.100
13	5	8	←	12	6	7	231064.910	-24	0.100
13	6	8	←	12	6	7	231064.910	-65	0.100
13	6	7	←	12	6	6	243867.304	-114	0.100
13	7	7	←	12	7	6	243851.679	32	0.100
13	13	1	←	12	12	0	336085.154	32	0.100
13	8	5	←	12	8	4	272002.215	-121	0.101
13	13	0	←	12	12	1	336139.911	27	0.100
14	0	14	←	13	0	13	179981.982	24	0.100
14	1	13	←	13	1	12	192665.771	-2	0.100
14	2	12	←	13	2	11	205349.365	39	0.100
14	4	10	←	13	4	9	230728.779	-18	0.100
15	0	15	←	14	0	14	192383.495	15	0.100
15	1	14	←	14	1	13	205066.357	19	0.100
15	3	12	←	14	3	11	230432.099	65	0.100
15	5	11	←	14	5	10	243120.957	62	0.100
15	6	10	←	14	6	9	255822.307	-210	0.101
15	10	5	←	14	10	4	325584.880	56	0.100
15	11	4	←	14	11	3	338643.066	-34	0.100
15	12	4	←	14	12	3	322817.708	80	0.100
15	12	3	←	14	12	2	334950.815	59	0.100
16	2	15	←	15	2	14	217466.671	18	0.100
16	2	14	←	15	2	13	230147.216	-200	0.100
16	3	13	←	15	3	12	242828.825	-15	0.105
16	9	7	←	15	9	6	319691.633	20	0.100
16	10	7	←	15	10	6	319468.730	9	0.100
16	10	6	←	15	10	5	334428.798	88	0.100
16	11	6	←	15	11	5	332050.687	-6	0.100
16	11	6	←	15	10	5	334972.546	-49	0.100
16	12	5	←	15	12	4	341730.456	14	0.100
17	1	16	←	16	1	15	229866.611	-90	0.100
17	2	15	←	16	2	14	242546.151	45	0.105
17	4	13	←	16	4	12	267907.558	68	0.105

Table 5.4: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
17	3	14	←	16	3	13	255225.428	-129	0.101
17	9	8	←	16	9	7	331748.254	31	0.100
17	10	8	←	16	10	7	331717.980	-4	0.100
17	13	4	←	16	11	5	461087.111	208	0.100
18	3	16	←	17	3	15	254944.511	4	0.100
18	4	14	←	17	4	13	280301.153	-57	0.105
18	1	17	←	17	1	16	242266.357	-106	0.105
18	3	15	←	17	3	14	267622.071	-15	0.105
18	5	13	←	17	5	12	292985.150	-7	0.105
18	17	2	←	17	16	1	461081.013	-4	0.100
18	17	1	←	17	16	2	461171.458	74	0.100
18	18	1	←	17	17	0	466225.257	90	0.100
18	18	0	←	17	17	1	466227.012	-54	0.100
19	1	18	←	19	1	19	234642.829	-6	0.104
19	1	18	←	18	1	17	254665.904	-18	0.100
19	2	17	←	18	2	16	267342.563	-27	0.100
19	3	16	←	18	3	15	280018.251	-108	0.105
19	4	15	←	18	4	14	292694.938	19	0.105
19	6	13	←	18	6	12	318062.711	8	0.105
19	7	12	←	18	7	11	330765.720	0	0.100
20	2	18	←	20	2	19	234559.882	37	0.104
20	2	18	←	19	2	17	279740.309	-22	0.100
20	1	19	←	19	1	18	267065.118	57	0.105
20	4	16	←	19	4	15	305088.388	-90	0.105
20	5	15	←	19	5	14	317764.979	-15	0.105
20	6	14	←	19	6	13	330447.295	-23	0.100
21	0	21	←	20	0	20	266787.453	-30	0.100
21	3	18	←	20	3	17	304809.855	-78	0.105
21	4	17	←	20	4	16	317481.692	-105	0.105
21	2	19	←	21	2	20	247233.571	-122	0.104
21	1	20	←	20	1	19	279463.840	-19	0.100
21	5	16	←	20	5	15	330155.096	-49	0.100
21	17	4	←	20	17	3	464495.316	111	0.100
21	19	3	←	21	17	4	143862.890	186	0.101
22	4	18	←	22	4	19	234366.465	22	0.104
22	3	19	←	22	3	20	247138.377	-34	0.104
22	4	18	←	21	4	17	329874.836	37	0.100
22	13	9	←	21	13	8	445043.710	-55	0.100
22	14	9	←	21	14	8	444942.779	63	0.100

Table 5.4: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
22	14	8	←	21	14	7	459297.773	9	0.100
22	15	8	←	21	15	7	458165.446	-17	0.100
22	17	5	←	21	17	4	496920.157	-26	0.100
22	18	4	←	21	18	3	483583.180	-39	0.100
22	19	4	←	21	19	3	472899.657	78	0.100
22	19	3	←	21	19	2	473787.461	48	0.100
22	21	2	←	21	21	1	464705.541	28	0.100
22	21	1	←	21	21	0	464707.777	-90	0.100
22	0	22	←	21	0	21	279187.137	-8	0.105
22	1	21	←	21	1	20	291862.274	-28	0.105
22	2	20	←	21	2	19	304534.735	36	0.105
22	1	21	←	22	1	22	272672.037	114	0.101
23	5	18	←	23	5	19	234254.583	18	0.104
23	4	19	←	23	4	20	247033.782	-120	0.104
23	1	22	←	23	1	23	285345.778	-41	0.104
23	2	21	←	22	2	20	316931.317	34	0.105
23	3	20	←	22	3	19	329599.925	-41	0.100
23	4	19	←	22	4	18	342267.455	28	0.100
23	13	10	←	22	13	9	457055.110	30	0.100
23	14	9	←	22	14	8	470481.471	84	0.100
23	15	9	←	22	15	8	470275.420	4	0.100
23	17	6	←	22	17	5	520813.234	49	0.100
23	21	3	←	22	21	2	489268.148	47	0.100
23	21	2	←	22	21	1	489302.548	8	0.100
23	2	21	←	23	2	22	272577.123	120	0.101
24	2	22	←	23	2	21	329327.451	12	0.100
24	6	18	←	24	6	19	234131.569	45	0.104
24	1	23	←	24	1	24	298018.392	-23	0.104
24	5	19	←	24	5	20	246919.535	40	0.104
24	2	22	←	24	2	23	285246.369	-25	0.104
24	0	24	←	23	0	23	303985.553	101	0.105
24	1	23	←	23	1	22	316658.137	90	0.105
24	3	21	←	23	3	20	341994.326	-6	0.100
24	13	12	←	23	13	11	456296.738	-78	0.100
24	12	12	←	23	12	11	456296.738	-153	0.100
24	13	12	←	23	12	11	456296.738	-160	0.100
24	12	12	←	23	13	11	456296.738	-71	0.100
24	14	10	←	23	14	9	482339.686	11	0.100
24	16	8	←	23	16	7	512009.385	-205	0.100

Table 5.4: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
24	21	4	←	23	21	3	514520.614	-14	0.100
24	21	3	←	23	21	2	514836.438	63	0.100
24	3	21	←	24	3	22	272473.786	-202	0.101
25	12	14	←	24	12	13	455819.348	-36	0.100
25	1	24	←	24	1	23	329055.230	-82	0.105
25	1	24	←	25	1	25	310689.619	-49	0.104
25	2	23	←	25	2	24	297914.155	-76	0.104
25	6	19	←	25	6	20	246794.623	141	0.104
25	3	22	←	25	3	23	285139.018	-50	0.104
25	4	21	←	25	4	22	272362.171	-189	0.101
26	1	25	←	25	2	24	341452.079	-69	0.100
26	10	17	←	25	10	16	442763.699	-3	0.100
26	11	16	←	25	11	15	455450.901	-29	0.100
26	4	23	←	25	4	22	366781.698	64	0.105
26	5	21	←	26	5	22	272241.543	-28	0.101
26	2	24	←	26	2	25	310580.432	-44	0.104
26	1	25	←	26	1	26	323359.717	177	0.104
26	8	18	←	26	8	19	233848.452	-104	0.104
26	7	19	←	26	7	20	246658.081	-35	0.104
26	4	22	←	26	4	23	285023.333	-34	0.104
26	3	23	←	26	3	24	297802.382	72	0.104
26	17	10	←	26	15	11	129088.513	-16	0.101
26	17	10	←	26	16	11	129087.161	-33	0.101
26	16	10	←	26	15	11	129065.127	27	0.101
26	16	10	←	26	16	11	129063.777	12	0.101
27	6	21	←	27	6	22	272110.977	-71	0.101
27	3	24	←	27	3	25	310463.612	-71	0.104
27	9	18	←	27	9	19	233686.762	-60	0.104
27	8	19	←	27	8	20	246509.566	-52	0.104
27	5	22	←	27	5	23	284898.692	-104	0.104
27	4	23	←	27	4	24	297682.353	135	0.104
27	3	25	←	27	1	26	323245.109	18	0.100
27	18	10	←	27	16	11	128399.546	41	0.101
27	18	10	←	27	17	11	128396.230	-165	0.101
27	17	10	←	27	16	11	128350.044	-25	0.101
27	17	10	←	27	17	11	128346.966	5	0.101
27	1	26	←	27	1	27	336027.882	-103	0.104
27	9	19	←	26	9	18	442466.433	166	0.100
27	2	25	←	26	2	24	366513.065	-85	0.105

Table 5.4: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
27	10	18	←	26	10	17	455133.635	84	0.100
27	11	16	←	26	11	15	480506.387	-3	0.100
28	9	19	←	28	9	20	246348.171	4	0.104
28	5	23	←	28	5	24	297553.650	148	0.104
28	6	22	←	28	6	23	284764.737	-95	0.104
28	4	25	←	28	2	26	323123.077	-82	0.100
28	7	21	←	28	7	22	271970.045	-148	0.101
28	19	10	←	28	17	11	127627.804	14	0.101
28	19	10	←	28	18	11	127620.800	-21	0.101
28	18	10	←	28	17	11	127527.175	79	0.101
28	18	10	←	28	18	11	127520.188	60	0.101
28	8	21	←	27	8	20	442186.164	-113	0.100
28	9	20	←	27	9	19	454842.810	15	0.100
28	10	18	←	27	10	17	480173.981	75	0.100
28	2	26	←	28	2	27	335908.073	34	0.104
28	1	27	←	28	1	28	348695.121	152	0.104
29	8	22	←	28	8	21	454566.935	-17	0.100
29	9	21	←	28	9	20	467219.220	28	0.100
29	10	20	←	28	10	19	479875.134	30	0.100
29	5	24	←	29	5	25	310205.541	-153	0.104
29	6	23	←	29	6	24	297415.803	114	0.104
29	7	22	←	29	7	23	284620.878	-58	0.104
29	10	19	←	29	10	20	246172.942	42	0.104
29	8	21	←	29	8	22	271818.268	-107	0.101
29	18	11	←	29	18	12	140975.220	52	0.101
29	18	11	←	29	17	12	140976.100	45	0.101
29	19	11	←	29	18	12	140990.260	14	0.101
29	19	11	←	29	17	12	140991.150	18	0.101
29	3	26	←	29	3	27	335780.548	-157	0.104
29	2	27	←	29	2	28	348569.443	162	0.104
29	1	28	←	29	1	29	361360.678	230	0.104
30	9	21	←	30	9	22	271654.859	-81	0.101
30	12	18	←	30	12	19	233108.954	204	0.104
30	6	24	←	30	6	25	310063.688	38	0.104
30	8	22	←	30	8	23	284466.559	20	0.104
30	11	19	←	30	11	20	245982.989	78	0.104
30	7	23	←	30	7	24	297268.374	89	0.104
30	19	11	←	30	19	12	140223.860	31	0.101
30	19	11	←	30	18	12	140225.850	-6	0.101

Table 5.4: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
30	20	11	←	30	18	12	140257.470	56	0.101
30	6	25	←	30	4	26	322855.376	5	0.100
30	9	22	←	29	9	21	479595.306	-4	0.100
30	4	26	←	30	4	27	335645.455	-195	0.104
30	3	27	←	30	2	28	348436.415	127	0.104
31	7	24	←	31	7	25	309912.409	99	0.104
31	9	22	←	31	9	23	284301.102	56	0.104
31	8	23	←	31	8	24	297110.704	-71	0.104
31	12	19	←	31	12	20	245777.420	168	0.104
31	7	25	←	31	5	26	322708.689	-43	0.100
31	10	21	←	31	10	22	271479.087	-110	0.101
31	5	26	←	31	5	27	335502.476	-44	0.104
31	4	27	←	31	4	28	348295.710	30	0.104
31	8	24	←	30	8	23	479326.758	-34	0.100
32	6	27	←	31	6	26	466422.817	-50	0.100
32	6	26	←	31	6	25	479065.073	-8	0.100
32	9	23	←	32	9	24	296942.566	-54	0.104
32	8	24	←	32	8	25	309751.239	38	0.104
32	10	22	←	32	10	23	284123.879	39	0.104
32	13	19	←	32	13	20	245555.099	175	0.104
32	8	25	←	32	6	26	322553.087	33	0.100
32	11	21	←	32	11	22	271290.272	-160	0.101
32	6	26	←	32	6	27	335350.862	-85	0.104
32	5	27	←	32	5	28	348147.181	53	0.104
33	4	29	←	32	4	28	466165.238	-72	0.100
33	5	28	←	32	5	27	478807.270	-86	0.100
33	8	25	←	32	8	24	516720.849	-52	0.100
33	9	25	←	33	7	26	322387.955	53	0.100
33	15	18	←	33	15	19	232368.189	146	0.101
33	9	24	←	33	9	25	309579.811	-25	0.104
33	14	19	←	33	14	20	245315.002	121	0.104
33	10	23	←	33	10	24	296763.201	-59	0.104
33	11	22	←	33	11	23	283934.162	-111	0.104
33	12	21	←	33	12	22	271087.785	-105	0.101
33	13	20	←	33	13	21	258217.494	-129	0.101
33	7	26	←	33	7	27	335190.604	51	0.104
33	6	27	←	33	6	28	347990.297	3	0.104
33	5	28	←	33	5	29	360789.370	196	0.104
34	3	31	←	33	3	30	465908.481	-51	0.100

Table 5.4: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
34	4	30	←	33	4	29	478551.641	-22	0.100
34	7	27	←	33	7	26	516461.972	102	0.100
34	16	18	←	34	16	19	232079.327	78	0.104
34	10	24	←	34	10	25	309397.795	89	0.104
34	11	23	←	34	11	24	296572.024	-86	0.104
34	15	19	←	34	15	20	245055.984	-35	0.104
34	12	22	←	34	12	23	283731.607	-66	0.104
34	13	21	←	34	13	22	270870.878	90	0.100
34	14	20	←	34	14	21	257982.174	32	0.100
34	9	25	←	34	9	26	322212.856	29	0.104
34	8	26	←	34	8	27	335021.070	132	0.104
34	7	27	←	34	7	28	347824.794	-32	0.104
34	6	28	←	34	6	29	360626.921	157	0.104
35	2	33	←	34	2	32	465651.310	24	0.100
35	3	32	←	34	3	31	478296.575	46	0.100
35	6	29	←	34	6	28	516207.921	185	0.100
35	14	21	←	35	14	22	270638.113	-188	0.100
35	16	19	←	35	16	20	244777.301	117	0.104
35	11	24	←	35	11	25	309204.260	-14	0.104
35	13	22	←	35	13	23	283515.310	-22	0.104
35	12	23	←	35	12	24	296368.367	-193	0.104
35	15	20	←	35	15	21	257729.108	-131	0.101
35	9	26	←	35	9	27	334841.693	0	0.104
35	8	27	←	35	8	28	347650.285	-73	0.104
35	7	28	←	35	7	29	360455.952	69	0.104
36	1	35	←	35	1	34	465392.450	-37	0.100
36	15	21	←	36	15	22	270389.637	65	0.100
36	17	19	←	36	17	20	244477.068	-85	0.104
36	12	24	←	36	12	25	308998.948	-44	0.104
36	14	22	←	36	14	23	283284.425	-92	0.104
36	13	23	←	36	13	24	296151.785	-191	0.104
36	16	20	←	36	16	21	257457.827	-72	0.101
36	2	34	←	35	2	33	478040.741	-2	0.100
36	11	25	←	36	11	26	321831.059	30	0.104
36	10	26	←	36	10	27	334652.310	-76	0.104
36	9	27	←	36	9	28	347466.464	-46	0.104
36	8	28	←	36	8	29	360276.109	-81	0.104
37	0	37	←	36	0	36	465131.214	55	0.100
37	1	36	←	36	1	35	477783.334	83	0.100

Table 5.4: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
37	16	21	←	37	16	22	270123.617	-82	0.101
37	17	20	←	37	17	21	257167.140	83	0.101
37	13	24	←	37	13	25	308781.226	-56	0.104
37	18	19	←	37	18	20	244154.578	-66	0.104
37	14	23	←	37	14	24	295921.606	-89	0.104
37	15	22	←	37	15	23	283038.445	-14	0.104
37	12	25	←	37	12	26	321623.351	36	0.104
37	11	26	←	37	11	27	334452.499	-77	0.104
37	10	27	←	37	10	28	347272.859	-30	0.104
37	9	28	←	37	9	29	360087.218	-119	0.104
38	16	22	←	38	16	23	282776.286	-69	0.104
38	15	23	←	38	15	24	295676.981	-44	0.104
38	14	24	←	38	14	25	308550.522	-22	0.104
38	13	25	←	38	13	26	321403.622	-76	0.104
38	11	27	←	38	11	28	347069.073	-11	0.104
38	12	26	←	38	12	27	334241.732	-69	0.104
38	10	28	←	38	10	29	359888.910	-50	0.104
38	0	38	←	37	0	37	477523.050	-20	0.100
39	20	19	←	39	20	20	243436.723	26	0.104
39	17	22	←	39	17	23	282497.397	29	0.104
39	15	24	←	39	15	25	308306.232	77	0.104
39	16	23	←	39	16	24	295417.146	-102	0.104
39	14	25	←	39	14	26	321171.649	15	0.104
39	13	26	←	39	13	27	334019.625	46	0.104
39	12	27	←	39	12	28	346854.694	21	0.104
39	11	28	←	39	11	29	359680.516	-162	0.104
40	1	39	←	39	1	38	514951.319	-18	0.100
40	6	34	←	39	6	33	578096.110	-8	0.100
40	20	20	←	40	20	21	256165.894	-103	0.100
40	21	19	←	40	21	20	243038.404	91	0.104
40	16	24	←	40	16	25	308047.277	-187	0.104
40	18	22	←	40	18	23	282200.767	148	0.104
40	17	23	←	40	17	24	295141.695	83	0.104
40	15	25	←	40	15	26	320926.632	79	0.104
40	14	26	←	40	14	27	333785.478	65	0.104
40	13	27	←	40	13	28	346629.271	58	0.104
40	12	28	←	40	12	29	359461.994	-108	0.104
41	0	41	←	40	0	40	514694.779	112	0.100
41	5	36	←	40	5	35	577855.272	-49	0.100

Table 5.4: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
41	22	20	←	41	21	21	255785.320	-7	0.101
41	22	19	←	41	22	20	242611.579	29	0.104
41	17	24	←	41	17	25	307773.966	172	0.104
41	19	22	←	41	19	23	281885.343	152	0.104
41	16	25	←	41	16	26	320668.049	181	0.104
41	15	26	←	41	15	27	333538.983	199	0.104
41	14	27	←	41	14	28	346392.204	-41	0.104
41	13	28	←	41	13	29	359232.859	32	0.104
42	19	23	←	42	19	24	294539.801	212	0.104
42	6	36	←	42	6	37	461612.829	-66	0.100
42	18	24	←	42	18	25	307484.554	115	0.104
42	22	20	←	42	22	21	255378.903	-24	0.101
42	17	25	←	42	17	26	320395.159	193	0.104
42	16	26	←	42	16	27	333279.114	-39	0.104
42	15	27	←	42	15	28	346143.206	-93	0.104
42	14	28	←	42	14	29	358992.553	124	0.104
43	2	41	←	42	2	40	564746.161	8	0.100
43	3	40	←	42	3	39	577372.836	-203	0.100
43	21	22	←	43	21	23	281194.224	-187	0.104
43	20	23	←	43	20	24	294211.443	-86	0.104
43	8	36	←	43	6	37	461387.711	6	0.100
43	18	25	←	43	18	26	320107.398	193	0.104
43	17	26	←	43	17	27	333005.844	-123	0.104
43	16	27	←	43	16	28	345881.873	-9	0.104
43	15	28	←	43	15	29	358740.469	-4	0.104
44	9	36	←	44	7	37	461154.521	8	0.100
44	22	22	←	44	22	23	280816.875	-123	0.104
44	20	24	←	44	20	25	306855.682	-21	0.104
44	21	23	←	44	21	24	293864.320	61	0.104
44	24	20	←	44	24	21	254483.018	-1	0.101
44	19	25	←	44	19	26	319803.760	-164	0.104
44	18	26	←	44	18	27	332718.605	-37	0.104
44	17	27	←	44	17	28	345607.361	-121	0.104
44	16	28	←	44	16	29	358476.514	6	0.104
45	0	45	←	44	0	44	564246.220	16	0.100
45	10	36	←	45	8	37	460913.198	81	0.100
45	21	24	←	45	21	25	306514.950	193	0.104
45	23	22	←	45	23	23	280416.670	-108	0.104
45	22	23	←	45	22	24	293496.662	-177	0.104

Table 5.4: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
45	25	20	←	45	25	21	253990.418	83	0.101
45	20	25	←	45	20	26	319484.473	42	0.104
45	18	27	←	45	18	28	345319.455	-114	0.104
46	0	46	←	45	0	45	576632.087	54	0.100
46	26	20	←	46	26	21	253465.390	-156	0.101
46	22	24	←	46	22	25	306155.029	42	0.104
46	24	22	←	46	24	23	279992.602	18	0.104
46	23	23	←	46	23	24	293108.167	-128	0.104
47	12	36	←	47	10	37	460404.869	11	0.100
47	25	22	←	47	25	23	279543.218	26	0.104
47	27	20	←	47	27	21	252906.921	108	0.100
47	22	25	←	47	22	26	318794.075	180	0.104
47	20	27	←	47	20	28	344700.864	-122	0.104
47	19	28	←	47	19	29	357607.869	91	0.104
48	13	36	←	48	11	37	460137.636	85	0.100
48	28	20	←	48	28	21	252312.263	105	0.101
48	23	25	←	48	23	26	318421.449	130	0.104
48	22	26	←	48	22	27	331415.388	-140	0.104
49	29	20	←	49	29	21	251679.480	0	0.101
49	26	23	←	49	26	24	291805.230	-151	0.104
49	25	24	←	49	25	25	304953.764	-53	0.104
49	27	22	←	49	27	23	278563.563	-21	0.104
49	24	25	←	49	24	26	318029.450	-9	0.104
50	26	24	←	50	26	25	304509.680	58	0.104
50	28	22	←	50	28	23	278030.754	184	0.104
50	25	25	←	50	25	26	317617.343	-119	0.104
50	24	26	←	50	24	27	330662.325	60	0.104
51	29	22	←	51	29	23	277466.615	-131	0.104
51	28	23	←	51	28	24	290810.962	59	0.104
51	27	24	←	51	27	25	304041.951	137	0.104
51	31	20	←	51	31	21	250290.953	85	0.101
51	26	25	←	51	26	26	317184.612	173	0.104
51	25	26	←	51	25	27	330257.507	-144	0.104
51	24	27	←	51	24	28	343276.163	171	0.104
52	30	22	←	52	30	23	276870.533	30	0.104
52	28	24	←	52	28	25	303549.457	162	0.104
52	29	23	←	52	29	24	290271.931	-208	0.104
52	32	20	←	52	32	21	249529.960	60	0.101
52	27	25	←	52	27	26	316729.469	16	0.104

Table 5.4: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
52	26	26	←	52	26	27	329833.272	-57	0.104
53	31	22	←	53	31	23	276240.058	-66	0.104
53	30	23	←	53	30	24	289703.597	-265	0.104
53	29	24	←	53	29	25	303030.988	82	0.104
53	27	26	←	53	27	27	329388.483	19	0.104
54	30	24	←	54	30	25	302485.642	210	0.104
54	29	25	←	54	29	26	315749.484	-162	0.104
56	31	25	←	56	31	26	314669.556	-95	0.104
57	32	25	←	57	32	26	314089.193	-33	0.104

Table 5.5: Rotational Constants of ν_7 in the S reduced Watson Hamiltonian.

Results of Analysis ν_7 (MHz) S

Constants	Value	σ
A	13028.9241	0.00144
B	12098.6285	0.00107
C	6201.6092	0.00104
Δ_J	-0.015574	0.00000137
Δ_{JK}	0.0261874	0.00000219
Δ_K	-0.011113	0.00000143
δ_1	-0.00128	0.00000141
δ_2	0.00051	0.00000171
H_J x E-07	0.2155	0.0072
H_{JJK} x E-06	-0.16064	0.00157
H_{JKK} x E-06	0.26394	0.00212
H_K x E-06	-0.16508	0.00105
h_1 x E-07	-0.114	0.018
h_2 x E-06	0.09	0.34
h_3 x E-07	0.12	0.05
rms	0.087414	

Table 5.6: Rotational Constants of ν_7 in the A reduced Watson Hamiltonian.

Results of Analysis ν_7 (MHz) A

Constants	Value	σ
A	13028.9757	0.00155
B	12098.5718	0.00107
C	6201.6147	0.00105
Δ_J	-0.014554	0.00000153
Δ_{JK}	0.020073	0.0000049
Δ_K	-0.006021	0.0000042
δ_J	-0.00128	0.00000119
δ_K	0.02787	0.0000237
H_J x E-07	0.3457	0.0124
H_{JK} x E-06	-0.43389	0.01114
H_{KJ} x E-06	0.976667	0.018223
H_K x E-06	-0.61682	0.00892
ϕ_J x E-07	-0.131	0.006
ϕ_{JK} x E-06	0.111	0.042
ϕ_K x E-07	0.10	0.37
rms	0.089792	

Table 5.7: Observed and calculated microwave transition frequencies for the $n = 6$ vibrational state of nitric acid .

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
7	5	3	←	6	5	2	141939.720	-31	0.101
8	2	6	←	7	2	5	131682.587	167	0.100
8	3	6	←	7	3	5	131680.830	-111	0.100
8	3	5	←	7	3	4	144232.919	-14	0.100
8	4	5	←	7	4	4	144166.757	36	0.100
8	5	4	←	7	5	3	156289.078	-9	0.101
9	1	8	←	8	1	7	131769.755	107	0.100
9	2	7	←	8	2	6	144238.193	0	0.100
9	9	1	←	8	8	0	231239.841	120	0.100
10	0	10	←	9	0	9	131869.072	31	0.100
10	1	9	←	9	1	8	144331.122	57	0.100
10	2	8	←	9	2	7	156796.728	261	0.100
10	4	6	←	9	4	5	181811.158	-36	0.100
10	8	2	←	9	6	3	270422.989	-142	0.101
11	0	11	←	10	0	10	144430.732	61	0.100
11	3	8	←	10	3	7	181827.509	-33	0.100
11	4	7	←	10	4	6	194327.197	-48	0.100
11	4	8	←	10	4	7	181827.535	29	0.100
11	5	7	←	10	5	6	194325.244	-8	0.100
11	6	6	←	10	6	5	206872.802	-36	0.100
11	8	4	←	10	8	3	229542.324	50	0.100
11	1	10	←	11	1	11	130803.439	-8	0.101
12	0	12	←	11	0	11	156991.728	12	0.100
12	2	10	←	11	2	9	181914.355	-7	0.100
12	3	9	←	11	3	8	194381.884	36	0.100
12	4	8	←	11	4	7	206866.210	-143	0.100
12	1	12	←	12	1	11	143264.257	-95	0.100
12	6	6	←	11	6	5	232134.472	2	0.100
12	7	6	←	11	7	5	231974.882	-50	0.100
12	8	5	←	11	8	4	244127.016	39	0.100
12	11	1	←	11	11	0	255272.667	-45	0.101
12	11	2	←	11	11	1	254437.067	3	0.101
12	3	10	←	12	1	11	130735.316	-65	0.101
12	1	11	←	12	1	12	143264.310	-42	0.101
13	1	12	←	12	1	11	182012.548	-4	0.100
13	2	11	←	12	2	10	194473.095	46	0.100
13	3	10	←	12	3	9	206937.255	-4	0.100

Table 5.7: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
13	6	7	←	12	6	6	244502.157	-130	0.100
13	6	8	←	12	6	7	231916.526	-7	0.100
13	8	5	←	12	8	4	272415.386	-162	0.101
13	7	6	←	12	7	5	257455.297	61	0.101
13	1	13	←	13	1	12	155724.706	-78	0.100
13	3	10	←	13	3	11	130651.091	-23	0.101
14	0	14	←	13	0	13	182111.816	-17	0.100
14	1	14	←	13	1	13	182111.860	26	0.100
14	1	13	←	13	1	12	194571.826	8	0.100
14	5	10	←	13	5	9	231962.539	45	0.100
14	8	6	←	13	8	5	282965.011	-13	0.100
14	2	12	←	14	2	13	155655.344	23	0.101
14	3	11	←	14	3	12	143112.817	-30	0.101
14	1	13	←	14	1	14	168184.742	-26	0.101
15	1	14	←	14	1	13	207130.419	68	0.100
15	3	12	←	15	3	13	155572.659	65	0.101
15	5	10	←	15	5	11	130423.281	-40	0.101
15	2	13	←	15	2	14	168113.827	-7	0.101
15	4	12	←	14	4	11	232048.561	-48	0.105
15	6	10	←	14	6	9	256992.109	34	0.100
15	9	6	←	14	7	7	452955.244	61	0.100
16	1	16	←	16	1	15	193103.417	-27	0.100
16	6	10	←	16	6	11	130273.785	-47	0.101
16	5	11	←	16	5	12	142894.401	-50	0.101
16	3	13	←	16	3	14	168030.651	-16	0.101
16	3	13	←	15	3	12	244603.759	-71	0.100
16	3	14	←	15	3	13	232145.751	-5	0.100
16	5	12	←	15	4	11	257065.634	106	0.105
16	14	2	←	15	12	3	445620.663	29	0.100
17	3	14	←	16	3	13	257158.488	20	0.101
17	2	15	←	16	2	14	244701.806	-46	0.100
17	7	10	←	17	7	11	130096.121	-49	0.101
17	4	13	←	17	4	14	167933.766	-12	0.101
17	6	11	←	17	6	12	142754.230	-46	0.101
17	3	15	←	17	3	14	180487.157	-126	0.100
17	5	13	←	16	4	12	269617.355	-53	0.105
17	12	5	←	16	10	6	480520.193	37	0.100
17	13	4	←	16	11	5	458422.301	59	0.100
17	14	3	←	16	12	4	456925.378	-93	0.100

Table 5.7: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
18	2	16	←	17	2	15	257257.138	59	0.105
18	1	17	←	17	1	16	244800.878	-92	0.100
18	7	11	←	17	8	10	319596.322	-4	0.105
18	5	13	←	17	5	12	294630.351	-62	0.100
18	8	10	←	18	8	11	129886.547	-56	0.101
18	5	13	←	18	5	14	167821.684	121	0.101
18	3	16	←	18	3	15	192942.480	-103	0.100
18	4	15	←	18	4	14	180390.234	-162	0.100
18	15	3	←	17	14	4	456147.433	106	0.100
18	16	3	←	17	15	2	454362.220	-46	0.100
18	18	0	←	17	17	1	465416.776	-225	0.100
18	18	1	←	17	17	0	465415.529	1	0.100
18	7	11	←	18	7	12	142589.840	-59	0.101
19	0	19	←	18	0	18	244898.118	-42	0.100
19	4	15	←	18	4	14	294720.156	105	0.100
19	2	18	←	18	2	17	257355.992	-7	0.105
19	6	13	←	18	6	12	319643.707	-87	0.105
19	7	12	←	18	8	11	332125.423	-47	0.105
19	8	11	←	18	9	10	344637.312	85	0.105
19	8	11	←	19	8	12	142398.360	-15	0.101
19	4	16	←	19	4	15	192844.873	-116	0.100
19	16	3	←	18	15	4	479932.499	18	0.100
19	17	3	←	18	16	2	480656.689	-51	0.100
20	0	20	←	19	0	19	257452.562	-56	0.101
20	2	18	←	19	2	17	282364.617	-45	0.100
20	3	17	←	19	3	16	294817.698	89	0.100
20	4	16	←	19	5	15	307270.329	-58	0.105
20	6	15	←	19	6	14	319725.193	-126	0.105
20	7	14	←	19	7	13	332186.133	67	0.105
20	8	13	←	19	8	12	344658.682	43	0.105
20	9	11	←	20	9	12	142176.460	-40	0.101
20	8	12	←	20	8	13	154892.990	-99	0.101
20	6	15	←	20	6	14	180153.027	-20	0.100
20	14	6	←	19	14	5	442954.400	90	0.100
20	15	5	←	19	15	4	451980.100	-17	0.100
20	16	4	←	19	16	3	442859.520	-76	0.100
21	6	16	←	21	6	15	192609.521	-47	0.100
21	7	15	←	21	7	14	180009.716	151	0.100
21	3	19	←	21	2	20	242848.405	-11	0.104

Table 5.7: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
21	10	11	←	21	10	12	141920.730	-51	0.100
21	1	20	←	20	1	19	282463.020	48	0.105
21	2	19	←	20	2	18	294917.001	101	0.105
21	4	18	←	20	4	17	307368.731	-24	0.105
21	6	16	←	20	5	15	332272.251	47	0.105
21	14	7	←	20	14	6	450745.773	47	0.100
21	14	7	←	20	15	6	443533.474	57	0.100
21	15	7	←	20	15	6	445257.531	50	0.100
21	16	6	←	20	16	5	453048.382	44	0.100
21	17	4	←	20	17	3	461891.293	18	0.100
21	18	4	←	20	18	3	450473.441	8	0.100
21	19	2	←	20	19	1	446271.326	26	0.100
21	19	3	←	20	19	2	446185.019	96	0.100
21	20	1	←	20	20	0	442590.874	38	0.100
21	20	2	←	20	20	1	442587.489	54	0.100
22	3	19	←	22	2	20	242752.512	237	0.104
22	7	16	←	22	7	15	192469.091	-57	0.100
22	2	20	←	22	2	21	255301.497	-133	0.102
22	1	22	←	21	1	21	282558.291	-32	0.105
22	2	21	←	21	2	20	295014.804	-7	0.105
22	3	20	←	21	3	19	307468.009	-15	0.105
22	5	18	←	21	5	17	332368.435	44	0.105
22	5	17	←	21	6	16	344818.452	58	0.105
22	13	9	←	21	13	8	445630.805	-80	0.100
22	13	9	←	21	14	8	445475.719	-46	0.100
22	14	8	←	21	14	7	459871.706	47	0.100
22	14	9	←	21	13	8	445653.431	154	0.100
22	14	9	←	21	14	8	445498.185	28	0.100
22	15	8	←	21	15	7	458466.675	9	0.100
22	16	6	←	21	17	5	459189.224	-16	0.100
22	20	2	←	21	20	1	467035.967	-23	0.100
22	20	3	←	21	20	2	466988.464	-17	0.100
22	21	1	←	21	21	0	463441.320	-98	0.100
22	21	2	←	21	21	1	463439.696	23	0.100
22	1	21	←	22	1	22	267849.059	-33	0.101
23	1	23	←	22	1	22	295109.315	-156	0.100
23	2	22	←	22	2	21	307565.457	-29	0.100
23	4	20	←	23	4	19	242646.630	84	0.100
23	13	10	←	22	13	9	457765.690	-42	0.100

Table 5.7: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
23	3	20	←	22	3	19	332467.740	-13	0.105
23	13	10	←	22	14	9	457743.259	-82	0.100
23	14	9	←	22	14	8	471048.913	183	0.100
23	14	10	←	22	13	9	457768.701	108	0.100
23	14	10	←	22	14	9	457746.169	-33	0.100
23	15	9	←	22	15	8	470779.322	-45	0.100
23	21	3	←	22	21	2	487785.918	-110	0.100
23	4	19	←	22	4	18	344915.842	-6	0.105
23	2	21	←	23	2	22	267754.114	-13	0.101
23	1	22	←	23	1	23	280305.270	162	0.102
24	6	19	←	24	5	20	242530.554	43	0.104
24	11	13	←	23	11	12	444759.791	20	0.100
24	0	24	←	23	0	23	307659.428	10	0.105
24	2	23	←	23	2	22	320115.031	84	0.105
24	4	21	←	23	4	20	345015.545	67	0.105
24	14	10	←	23	14	9	483008.387	33	0.100
24	15	9	←	23	15	8	496612.678	1	0.100
24	15	10	←	23	15	9	482965.261	-183	0.100
24	16	9	←	23	16	8	496090.342	3	0.100
24	1	23	←	24	1	24	292760.726	89	0.101
24	2	22	←	24	2	23	280206.028	124	0.102
24	4	20	←	24	4	21	255093.360	129	0.102
24	3	21	←	24	3	22	267650.522	-277	0.101
25	6	20	←	25	6	19	242403.418	4	0.100
25	1	24	←	25	1	25	305215.757	91	0.102
25	4	21	←	25	4	22	267538.470	-80	0.101
25	5	20	←	25	5	21	254974.571	27	0.102
25	2	23	←	25	2	24	292656.980	28	0.101
25	10	15	←	24	10	14	444737.532	25	0.100
25	2	23	←	24	2	22	345114.256	66	0.105
25	3	22	←	24	3	21	357561.977	37	0.105
25	11	14	←	24	11	13	457246.663	-7	0.100
26	8	19	←	26	7	20	242264.235	-220	0.104
26	10	16	←	25	10	15	457251.022	41	0.100
26	2	24	←	25	3	23	357660.259	-75	0.105
26	6	20	←	26	6	21	254845.272	-29	0.101
26	1	25	←	26	1	26	317670.021	-158	0.102
26	4	22	←	26	4	23	279982.557	20	0.102
26	3	23	←	26	3	24	292545.347	48	0.101

Table 5.7: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
26	2	24	←	26	2	25	305107.202	-60	0.102
26	5	21	←	26	5	22	267416.894	97	0.101
27	8	19	←	26	8	18	444857.388	61	0.100
27	0	27	←	26	0	26	345301.624	64	0.105
27	8	20	←	27	8	19	242112.773	-25	0.100
27	4	23	←	27	4	24	292425.033	-178	0.101
27	7	20	←	27	7	21	254704.830	38	0.102
27	5	22	←	27	5	23	279857.428	94	0.102
27	2	25	←	27	2	26	317556.781	-45	0.102
27	3	24	←	27	3	25	304991.200	153	0.102
27	6	21	←	27	6	22	267284.834	-87	0.101
27	2	26	←	27	0	27	330124.285	121	0.101
27	10	18	←	26	10	17	457306.726	-58	0.100
27	2	26	←	26	1	25	357755.527	-16	0.105
27	17	11	←	26	17	10	545635.273	223	0.100
28	8	20	←	27	8	19	457387.885	17	0.100
28	1	28	←	27	0	27	357846.295	77	0.105
28	7	21	←	27	7	20	444948.383	-20	0.100
28	14	15	←	27	14	14	519764.447	-90	0.100
28	7	21	←	28	7	22	267142.047	-235	0.101
28	4	24	←	28	4	25	304866.653	62	0.102
28	1	27	←	28	1	28	342577.679	79	0.102
28	8	20	←	28	8	21	254552.368	105	0.102
28	5	23	←	28	5	24	292296.144	-61	0.101
28	6	22	←	28	6	23	279722.267	-115	0.101
28	2	26	←	28	2	27	330005.632	2	0.101
29	6	23	←	28	6	22	445046.730	-61	0.100
29	8	22	←	28	8	21	457481.540	-67	0.100
29	6	23	←	29	6	24	292157.823	53	0.101
29	5	24	←	29	5	25	304733.485	38	0.102
29	10	20	←	29	10	19	241768.046	228	0.100
29	4	25	←	29	4	26	317306.841	159	0.102
29	4	26	←	29	2	27	329879.509	-18	0.101
29	7	22	←	29	7	23	279577.095	-3	0.101
29	2	27	←	29	2	28	342453.756	96	0.102
29	1	28	←	29	1	29	355030.640	169	0.102
29	8	21	←	29	8	22	266988.329	125	0.101
29	13	17	←	28	13	16	519735.026	26	0.100
29	14	15	←	28	14	14	544783.723	56	0.100

Table 5.7: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
30	1	29	←	29	1	28	395383.419	-36	0.100
30	6	24	←	29	6	23	457581.173	-67	0.100
30	11	20	←	29	11	19	507321.424	43	0.100
30	11	20	←	30	11	19	241572.578	-14	0.100
30	10	20	←	30	10	21	254207.952	-10	0.102
30	3	27	←	30	3	28	342322.204	-40	0.102
30	5	25	←	30	5	26	317169.163	78	0.102
30	6	24	←	30	6	25	304591.170	20	0.102
30	7	23	←	30	7	24	292009.218	-155	0.101
30	5	26	←	30	3	27	329745.449	-41	0.101
30	9	21	←	30	9	22	266822.106	126	0.101
30	8	22	←	30	8	23	279420.704	-167	0.101
30	2	28	←	30	2	29	354900.862	-38	0.102
30	12	19	←	29	12	18	519770.431	37	0.100
31	4	27	←	30	4	26	445248.670	-35	0.100
31	5	26	←	30	5	25	457682.771	11	0.100
31	9	22	←	31	11	21	266642.856	-13	0.100
31	8	23	←	31	8	24	291850.587	125	0.101
31	3	28	←	31	3	29	354763.969	35	0.102
31	4	27	←	31	4	28	342183.116	100	0.102
31	6	25	←	31	6	26	317022.558	-13	0.102
31	7	24	←	31	7	25	304439.201	-10	0.102
31	9	22	←	31	9	23	279253.062	-1	0.101
31	5	26	←	31	5	27	329603.269	130	0.101
31	11	20	←	31	11	21	254014.346	-155	0.101
31	12	20	←	30	12	19	532281.476	-32	0.100
32	8	24	←	31	8	23	507499.548	-145	0.100
32	11	21	←	31	11	20	544792.806	-9	0.100
32	17	15	←	31	17	14	619893.053	-109	0.100
32	11	21	←	32	11	22	266449.979	-118	0.101
32	9	23	←	32	9	24	291680.524	71	0.101
32	7	25	←	32	7	26	316866.628	-67	0.102
32	5	27	←	32	5	28	342035.769	149	0.102
32	8	24	←	32	8	25	304277.049	-76	0.102
32	6	26	←	32	6	27	329452.032	-43	0.101
32	12	20	←	32	12	21	253805.592	-42	0.102
32	10	22	←	32	10	23	279073.081	75	0.101
33	2	31	←	32	2	30	445442.119	-76	0.100
33	3	30	←	32	3	29	457881.830	41	0.100

Table 5.7: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
33	5	28	←	33	7	27	341879.854	164	0.100
33	10	23	←	33	10	24	291498.642	-98	0.101
33	5	28	←	33	5	29	354466.631	95	0.102
33	9	24	←	33	9	25	304104.402	39	0.102
33	8	25	←	33	8	26	316700.839	-150	0.102
33	8	26	←	33	6	27	329291.874	-14	0.101
33	13	20	←	33	13	21	253580.359	-50	0.102
33	11	22	←	33	11	23	278880.033	32	0.101
33	12	21	←	33	12	22	266242.846	-7	0.101
33	11	23	←	32	11	22	544873.953	-15	0.100
33	16	18	←	32	16	17	607149.494	-29	0.100
33	17	16	←	32	17	15	632272.855	20	0.100
34	6	28	←	33	6	27	507703.203	-78	0.100
34	12	23	←	33	12	22	569814.092	-232	0.100
34	15	19	←	34	17	18	227839.422	-40	0.100
34	10	24	←	34	10	25	303920.534	164	0.102
34	6	28	←	34	6	29	354305.399	-35	0.102
34	7	27	←	34	7	28	341714.771	-72	0.102
34	9	25	←	34	9	26	316525.027	58	0.102
34	11	23	←	34	11	24	291304.731	35	0.101
34	14	20	←	34	14	21	253337.847	23	0.102
34	13	21	←	34	13	22	266020.178	-108	0.101
34	9	26	←	34	7	27	329122.228	78	0.101
34	12	22	←	34	12	23	278673.155	-162	0.101
35	0	35	←	34	0	34	445615.989	5	0.100
35	5	30	←	34	5	29	507805.591	-51	0.100
35	5	31	←	34	5	30	495377.781	-72	0.100
35	8	28	←	34	8	27	532650.239	-46	0.100
35	16	19	←	35	18	18	227514.394	-59	0.100
35	15	20	←	35	15	21	253076.824	-3	0.102
35	11	24	←	35	11	25	303724.666	95	0.102
35	8	27	←	35	8	28	341540.843	159	0.102
35	10	25	←	35	10	26	316338.194	66	0.102
35	7	28	←	35	7	29	354135.620	23	0.102
35	12	23	←	35	12	24	291097.542	-113	0.101
35	9	26	←	35	9	27	328942.343	-66	0.101
35	13	22	←	35	13	23	278452.129	-65	0.101
35	14	21	←	35	14	22	265781.429	-77	0.101
35	24	11	←	35	24	12	130857.105	-62	0.100

Table 5.7: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
35	18	18	←	34	18	17	657096.366	-236	0.100
36	0	36	←	35	0	35	458147.992	119	0.100
36	7	29	←	35	7	28	545172.576	30	0.100
36	8	28	←	36	10	27	341356.906	109	0.100
36	12	24	←	36	12	25	303516.343	-23	0.102
36	11	25	←	36	11	26	316139.852	-86	0.102
36	16	20	←	36	16	21	252796.287	-27	0.102
36	8	28	←	36	8	29	353956.824	170	0.102
36	13	23	←	36	13	24	290877.044	112	0.101
36	10	26	←	36	10	27	328752.193	-11	0.101
36	15	21	←	36	15	22	265525.636	57	0.101
36	14	22	←	36	14	23	278215.869	35	0.101
36	17	19	←	36	19	18	227163.145	16	0.100
37	1	36	←	36	1	35	483125.608	13	0.100
37	4	34	←	36	4	33	508001.911	-95	0.100
37	9	28	←	37	11	27	341162.714	-41	0.100
37	14	23	←	37	14	24	290641.840	34	0.101
37	15	22	←	37	15	23	277963.566	166	0.101
37	17	20	←	37	17	21	252495.273	151	0.102
37	9	28	←	37	9	29	353768.236	13	0.102
37	13	24	←	37	13	25	303295.007	-125	0.102
37	11	26	←	37	11	27	328551.021	-30	0.101
37	16	21	←	37	16	22	265251.506	-18	0.101
37	18	19	←	37	20	18	226783.821	59	0.100
37	12	25	←	37	12	26	315929.722	-133	0.101
38	3	35	←	37	3	34	520527.486	63	0.100
38	10	28	←	38	12	27	340958.075	-38	0.100
38	14	24	←	38	14	25	303060.140	-74	0.101
38	15	23	←	38	15	24	290391.476	-49	0.101
38	18	20	←	38	18	21	252171.966	-57	0.102
38	13	26	←	38	11	27	328338.432	-15	0.101
38	16	22	←	38	16	23	277693.750	-268	0.101
38	19	19	←	38	21	18	226374.492	-21	0.100
38	10	28	←	38	10	29	353569.940	34	0.102
39	1	38	←	39	3	37	466887.393	-151	0.100
39	2	37	←	38	2	36	520618.122	120	0.100
39	2	37	←	39	4	36	454258.617	-11	0.100
39	4	35	←	38	4	34	545477.908	76	0.100
39	11	28	←	39	13	27	340742.603	196	0.100

Table 5.7: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
39	16	23	←	39	16	24	290125.247	-58	0.101
39	15	24	←	39	15	25	302810.947	13	0.102
39	13	26	←	39	13	27	328113.996	127	0.101
39	19	20	←	39	19	21	251825.719	-10	0.102
39	18	21	←	39	18	22	264644.832	-44	0.101
39	17	22	←	39	17	23	277406.811	34	0.101
39	11	28	←	39	11	29	353361.331	39	0.102
39	28	12	←	39	26	13	142108.430	-71	0.101
40	3	37	←	39	3	36	545572.514	131	0.100
40	3	37	←	40	5	36	454061.581	-64	0.100
40	16	24	←	40	16	25	302546.526	-54	0.102
40	12	28	←	40	12	29	353141.933	-19	0.101
40	14	26	←	40	14	27	327876.741	-31	0.101
40	17	23	←	40	17	24	289842.346	18	0.101
40	18	22	←	40	18	23	277100.695	-18	0.101
40	19	21	←	40	19	22	264310.108	38	0.101
40	5	35	←	39	5	34	570417.867	100	0.100
40	12	28	←	40	14	27	340514.930	-225	0.100
40	20	20	←	40	20	21	251454.958	81	0.101
41	2	39	←	40	2	38	545661.356	1	0.100
41	13	28	←	41	13	29	352911.435	-7	0.101
41	13	28	←	41	15	27	340275.900	41	0.100
41	17	24	←	41	17	25	302266.363	-51	0.102
41	18	23	←	41	18	24	289541.716	-14	0.101
41	15	26	←	41	15	27	327626.681	87	0.101
41	20	21	←	41	20	22	263952.741	41	0.101
41	19	22	←	41	19	23	276774.965	140	0.101
41	21	20	←	41	21	21	251058.014	-9	0.101
42	1	41	←	41	1	40	545743.851	77	0.100
42	5	37	←	42	7	36	453644.788	-23	0.100
42	19	23	←	42	19	24	289222.688	68	0.101
42	22	20	←	42	22	21	250633.712	66	0.101
42	16	26	←	42	16	27	327362.650	-91	0.101
42	18	24	←	42	18	25	301969.754	90	0.102
42	20	22	←	42	20	23	276428.050	-4	0.101
42	21	21	←	42	21	22	263571.677	165	0.101
42	15	27	←	42	15	28	340024.153	154	0.101
43	1	43	←	42	1	42	545818.819	74	0.100
43	15	28	←	43	15	29	352415.067	15	0.101

Table 5.7: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
43	2	41	←	42	2	40	570696.821	282	0.100
43	3	40	←	43	5	39	491329.593	-90	0.100
43	19	24	←	43	19	25	301655.340	-179	0.102
43	20	23	←	43	20	24	288883.922	-130	0.101
43	17	26	←	43	17	27	327084.646	40	0.101
43	16	27	←	43	16	28	339759.010	-23	0.101
43	22	21	←	43	22	22	263165.228	50	0.101
43	21	22	←	43	21	23	276059.208	-86	0.101
43	6	37	←	43	8	36	453424.546	8	0.100
43	23	20	←	43	23	21	250180.179	52	0.101
43	18	25	←	43	18	26	314385.715	-181	0.101
43	7	36	←	42	7	35	632773.438	96	0.100
44	1	43	←	43	1	42	570776.877	-67	0.100
44	7	37	←	44	9	36	453195.992	-71	0.100
44	20	24	←	44	20	25	301323.147	7	0.102
44	16	28	←	44	16	29	352148.220	25	0.101
44	19	26	←	44	17	27	326791.739	191	0.101
44	21	23	←	44	21	24	288525.212	168	0.101
44	22	22	←	44	22	23	275667.371	-6	0.101
44	23	21	←	44	23	22	262732.099	-196	0.101
44	24	20	←	44	24	21	249695.665	-81	0.101
44	17	27	←	44	17	28	339480.454	51	0.101
44	19	25	←	44	19	26	314075.047	-124	0.101
45	25	20	←	45	25	21	249178.594	-85	0.104
45	0	45	←	44	0	44	570849.429	-159	0.100
45	7	38	←	45	9	37	465590.059	-87	0.100
45	24	21	←	45	24	22	262271.295	-88	0.101
45	19	26	←	45	19	27	326483.085	182	0.101
45	21	24	←	45	21	25	300971.742	102	0.102
45	22	23	←	45	22	24	288144.745	184	0.101
45	17	28	←	45	17	29	351868.218	4	0.100
45	8	37	←	45	10	36	452959.161	-1	0.100
45	23	22	←	45	23	23	275250.911	-166	0.101
45	18	27	←	45	18	28	339187.524	0	0.101
45	20	25	←	45	20	26	313747.268	7	0.101
46	26	20	←	46	25	21	248626.938	-36	0.104
46	9	37	←	46	11	36	452713.542	-53	0.100
46	18	28	←	46	18	29	351574.516	-58	0.101
46	23	23	←	46	23	24	287741.533	16	0.101

Table 5.7: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
46	21	26	←	46	19	27	326157.769	-211	0.101
46	22	24	←	46	22	25	300599.935	-162	0.101
46	25	21	←	46	25	22	261780.958	87	0.101
46	24	22	←	46	24	23	274809.030	-69	0.101
46	21	25	←	46	21	26	313401.271	-95	0.101
47	27	20	←	47	26	21	248038.736	188	0.104
47	2	46	←	46	2	45	608310.693	30	0.100
47	10	37	←	47	12	36	452459.106	-11	0.100
47	23	24	←	47	23	25	300207.629	84	0.101
47	26	21	←	47	26	22	261259.156	66	0.101
47	24	23	←	47	24	24	287314.917	147	0.101
47	25	22	←	47	25	23	274340.100	24	0.101
47	21	26	←	47	21	27	325815.935	-125	0.101
47	19	28	←	47	19	29	351266.778	58	0.101
47	22	25	←	47	22	26	313036.673	13	0.101
48	28	20	←	48	27	21	247410.998	-168	0.104
48	1	48	←	47	1	47	608379.614	-189	0.100
48	8	40	←	48	10	39	490111.378	168	0.100
48	29	19	←	48	29	20	233910.909	-48	0.104
48	24	24	←	48	24	25	299793.041	74	0.101
48	25	23	←	48	25	24	286863.080	-40	0.101
48	27	21	←	48	27	22	260704.427	161	0.101
48	22	26	←	48	22	27	325456.457	68	0.101
48	20	28	←	48	20	29	350944.035	-35	0.101
48	11	37	←	48	13	36	452195.464	-13	0.100
48	26	22	←	48	26	23	273842.494	-68	0.101
48	21	27	←	48	21	28	338217.354	146	0.101
48	23	25	←	48	23	26	312652.300	29	0.101
49	29	20	←	49	29	21	246742.546	115	0.104
49	12	37	←	49	14	36	451922.467	54	0.100
49	21	28	←	49	21	29	350605.868	-156	0.101
49	28	21	←	49	28	22	260114.490	-19	0.101
49	27	22	←	49	27	23	273315.155	126	0.101
49	24	26	←	49	22	27	325078.125	-55	0.101
49	26	23	←	49	26	24	286385.131	-171	0.101
49	25	24	←	49	25	25	299355.290	-7	0.101
49	22	27	←	49	22	28	337860.976	-39	0.101
49	24	25	←	49	24	26	312247.209	-81	0.101
50	30	20	←	50	30	21	246029.827	72	0.104

Table 5.7: (Continued)

J'	K'_A	K'_C		J''	K''_A	K''_C	Observed(MHz)	O-C(kHz)	Weighting
50	27	23	←	50	27	24	285879.875	-104	0.101
50	28	22	←	50	28	23	272755.878	26	0.101
50	24	26	←	50	24	27	324680.775	157	0.101
50	22	28	←	50	22	29	350251.959	1	0.101
50	29	21	←	50	29	22	259487.852	49	0.101
50	23	27	←	50	23	28	337487.416	132	0.101
50	25	25	←	50	25	26	311820.992	224	0.101
51	31	20	←	51	31	21	245270.407	62	0.104
51	14	37	←	51	16	36	451346.928	3	0.100
51	23	28	←	51	23	29	349881.234	17	0.101
51	27	24	←	51	27	25	298406.088	-64	0.101
51	30	21	←	51	30	22	258822.016	31	0.101
51	29	22	←	51	29	23	272163.285	-21	0.101
51	24	27	←	51	24	28	337095.399	132	0.101
51	26	25	←	51	26	26	311371.534	-168	0.101
52	32	20	←	52	32	21	244461.089	-80	0.104
52	15	37	←	52	17	36	451043.960	24	0.100
52	31	21	←	52	31	22	258114.721	-15	0.102
52	28	24	←	52	28	25	297892.351	92	0.101
52	24	28	←	52	24	29	349493.196	71	0.101
52	29	23	←	52	29	24	284781.057	-33	0.101
52	25	27	←	52	25	28	336684.121	-67	0.101
53	15	38	←	53	17	37	463381.780	5	0.100
53	25	28	←	53	25	29	349086.879	-96	0.101
53	30	23	←	53	30	24	284184.417	-29	0.101
53	29	24	←	53	29	25	297350.543	115	0.101
53	26	27	←	53	26	28	336253.358	117	0.101
53	32	21	←	53	32	22	257363.559	-3	0.102
54	32	22	←	54	32	23	270166.355	-106	0.102
54	16	38	←	54	18	37	463061.846	10	0.100
54	31	23	←	54	31	24	283553.919	-206	0.101
54	30	24	←	54	30	25	296779.547	269	0.101
54	28	27	←	54	26	28	335801.527	-48	0.101
55	29	27	←	55	27	28	335328.253	-54	0.101
56	34	22	←	56	34	23	268631.271	114	0.102
56	29	27	←	56	29	28	334832.290	-219	0.101
57	30	27	←	57	30	28	334313.165	-46	0.101

Table 5.8: Rotational Constants of ν_6 in the S reduced Watson Hamiltonian.

Results of Analysis ν_6 (MHz) S

Constants	Value	σ
A	13006.2131	0.00119
B	12057.4905	0.00096
C	6282.3422	0.00057
Δ_J	-0.015010	0.00000093
Δ_{JK}	0.0249548	0.00000120
Δ_K	-0.012181	0.00000090
δ_1	-0.00146	0.00000114
δ_2	0.0003	0.00000089
H_J x E-07	0.1434	0.0043
H_{JJK} x E-07	-0.5952	0.0091
H_{JKK} x E-07	0.6259	0.0109
H_K x E-07	0.1035	0.0061
h_1 x E-07	-0.1218	0.0105
h_2 x E-08	-0.537	0.190
h_3 x E-09	0.2	0.4
rms	0.090631	

Table 5.9: Rotational Constants of ν_6 in the A reduced Watson Hamiltonian.

Results of Analysis ν_6 (MHz) A

Constants	Value	σ
A	13006.2615	0.00162
B	12057.4482	0.00146
C	6282.3473	0.00060
Δ_J	-0.014496	0.00000214
Δ_{JK}	0.021802	0.0000094
Δ_K	-0.009550	0.0000075
δ_J	-0.00144	0.00000201
δ_K	0.01404	0.000036
H_J x E-07	-0.91512	0.03108
H_{JK} x E-07	-0.82537	0.30133
H_{KJ} x E-07	0.168285	0.005921
H_K x E-07	-0.147966	0.003277
ϕ_J x E-07	0.665	0.078
ϕ_{JK} x E-08	-0.26627	0.00773
ϕ_K x E-09	-0.56478	0.01248
rms	.12479	

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